4.4 LAKE OZETTE TRIBUTARIES

Sockeye salmon spawn in the three largest tributaries to Lake Ozette, i.e., Umbrella Creek, Big River, and Crooked Creek. Habitat conditions in these streams are discussed in detail in this section. Similar information is provided for Coal Creek mainly because of its size, its sediment and hydrologic influence on the Ozette River and Lake Ozette, and its potential for future colonization by sockeye. Detailed information for Siwash Creek is included because it has a large population of kokanee; documenting and understanding habitat elements that are capable of sustaining a healthy population of kokanee may provide critical insight into factors affecting tributary spawning sockeye salmon in the watershed.

4.4.1 Umbrella Creek

Umbrella Creek is the third largest tributary to Lake Ozette. Umbrella Creek enters the lake at the northwest edge of Umbrella Bay (Figure 3.16). The Umbrella Creek watershed drains approximately 10.6 mi^2 (27.5km^2) and has several significant tributaries. The two largest tributaries are the East and West Branches of Umbrella Creek, followed by Hatchery Creek (WRIA# 20.0056) and Elk Creek. The mainstem flows predominately south-southwest from its headwaters at Elk Lake. The course of the mainstem is almost exclusively underlain by Pleistocene age glacial till, drift, and outwash deposits. The majority of the main channel sections of large tributaries to Umbrella Creek are associated with broad, low relief glacial deposits.

4.4.1.1 Umbrella Creek Floodplain Conditions

Smith (2000) rated the overall floodplain condition in Umbrella Creek as good. But Smith (2000) also cites J. Freudenthal as stating that channel incision is a problem in Umbrella Creek. Herrera (2006) reports that the lower 0.75 mile (1.2 km) of Umbrella Creek has undergone approximately 3.3 feet (1m) of channel incision over the last 50 years. No formal field-based assessment of Umbrella Creek floodplain conditions has been conducted. Short reaches of Umbrella Creek were identified by Smith (2000) as having riparian adjacent roads (RM 6.0-6.3, RM 8.0-8.2). Floodplain conditions in two of the largest tributaries to Umbrella Creek (West Branch and Hatchery Creek) were rated as poor by Smith (2000), based upon riparian-adjacent roads.

4.4.1.2 Umbrella Creek Riparian Conditions

Riparian conditions in Umbrella Creek vary considerably depending on location. Nearly all (>95%) of the old growth riparian forest has been harvested along the mainstem of Umbrella Creek. Meyer and Brenkman (2001) reported that 93% of forest within the Umbrella Creek watershed was 40 years old or less. Less than 0.1% of the forest within the watershed was classified as >80 years old (Meyer and Brenkman 2001). Smith (2000) rated the riparian conditions along Umbrella Creek as poor. However, the data used by Smith (2000) were limited to the lower mile of Umbrella Creek. Orthophotos taken in the summer of 2000 show that while it is true that the majority of riparian forests have been converted to stands dominated by red alder (*Alnus rubra*), some residual large conifer trees are still present in small patches. These patches are mostly along the west side of the lower 2 miles of the creek. Stands dominated by red alder or mixed alder/conifer predominate in the riparian areas from the Hoko-Ozette Road upstream past the confluence with the East Branch of Umbrella Creek. Prior to timber harvest, riparian forests here were composed primarily of Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*). Residual in-channel LWD and standing trees provide evidence of the massive trees that once grew along Umbrella Creek. Riparian conditions in the primary tributaries to Umbrella Creek are also highly degraded from the pre-disturbance condition. Extensive stands of young to medium-aged red alders dominate the riparian composition of both the East and West Branches of Umbrella Creek.

4.4.1.3 Umbrella Creek Pool and LWD Conditions

Pool and LWD habitat data were collected by the Makah Tribe during the summer of 1999 in Umbrella Creek and are summarized in detail by Haggerty and Ritchie (2004). Field data were collected for almost 11,000 meters of channel within the mainstem of Umbrella Creek and several thousand meters in tributaries. Channel attribute data for Lake Ozette tributaries can be found in Appendix D. LWD and habitat data were collected in 20 habitat segments encompassing the 11,000 meters of channel in the mainstem. A total of 4,734 pieces of LWD were inventoried, of which 77%, 21%, and 2% were categorized as conifer, deciduous, and unknown respectively. Only 1% of the pieces inventoried were classified as key pieces[13]. Approximately 81% of the pieces inventoried were <50cm in diameter. Haggerty and Ritchie (2004) developed a habitat and LWD rating system to evaluate habitat and LWD conditions within the watershed. The results are included in Appendix E. Figure 4.48 depicts the frequency of LWD > 50 cm diameter and total LWD piece frequency per 100 meters for each habitat segment in Umbrella Creek watershed.

Pool habitat conditions were also evaluated for the same habitat segments mentioned above. Haggerty and Ritchie (2004) rated several pool habitat condition variables including: pool frequency, percent pools (by length), average maximum and residual pool depth, average pool length, pools >1m deep/km, pool cover, and percent of pools formed by LWD. Figure 4.49 depicts pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments

[13] Key piece is defined as a log and/or rootwad that is: (1) independently stable in the stream bankfull width (not functionally held by another factor, i.e., pinned by another log, buried, trapped against a rock or bedform, etc.), and (2) is retaining (or has the potential to retain) other pieces of organic debris. Without the Key Piece, the retained organic debris will likely become mobilized in a high flow (approximately equal to or greater than a 10 year event). (From WDNR 1997)

surveyed in the Umbrella Creek watershed. A total of 279 pools were documented in the mainstem of Umbrella Creek. The highest quality pools were most often associated with the largest LWD pieces. Pools formed by key-piece-sized LWD averaged nearly 1.8 times deeper than pools formed by medium or small LWD, or free-formed pools without LWD.

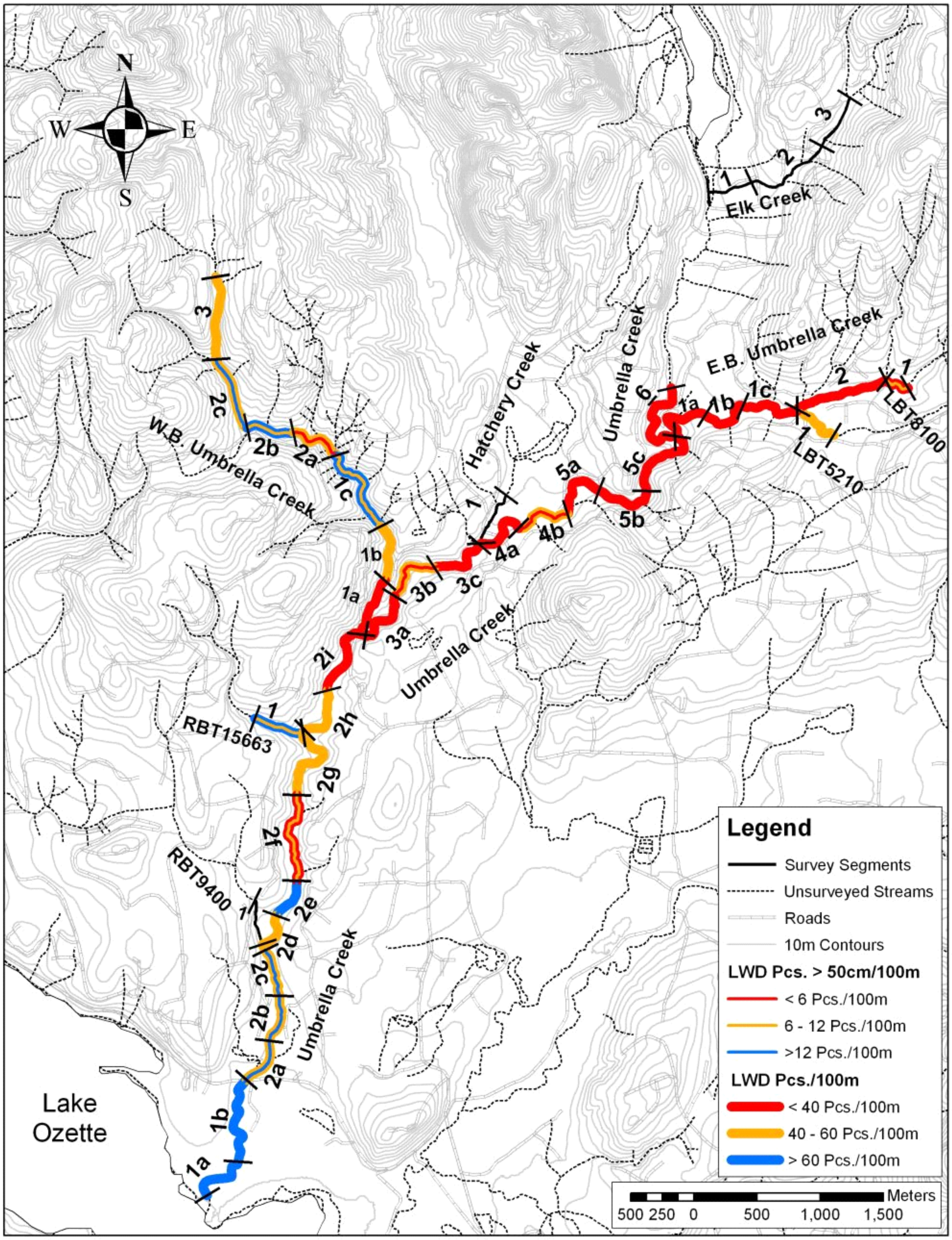

Figure 4.48. Umbrella Creek watershed LWD >50cm diameter and total LWD piece count per 100 meters calculated for each habitat segment inventoried (source: Haggerty and Ritchie 2004).

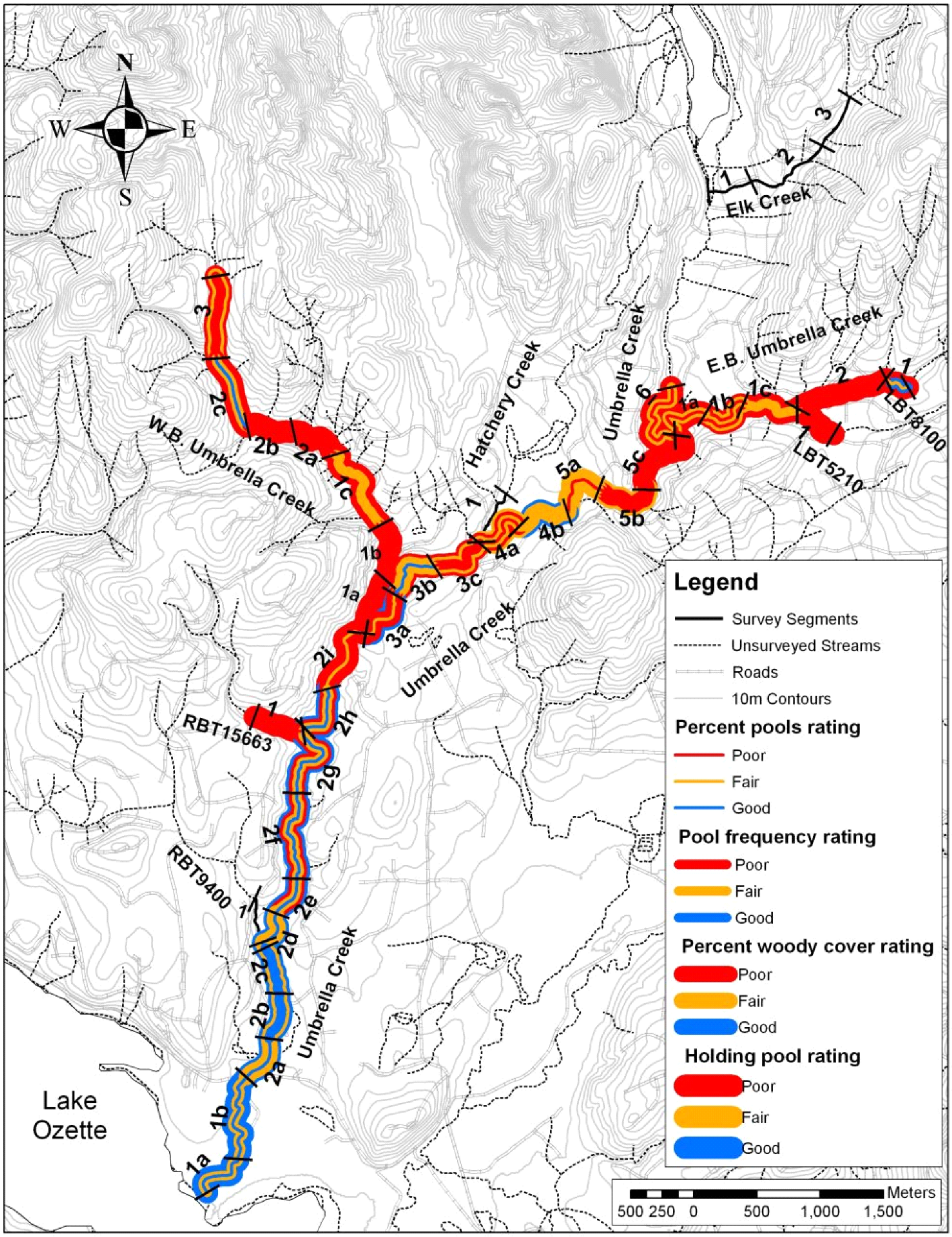

Figure 4.49. Pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in the Umbrella Creek watershed (source: Haggerty and Ritchie 2004).

Riparian forest removal has dramatically decreased the quantity and quality of trees available for recruitment into Umbrella Creek. Habitat and LWD data collected in Umbrella Creek illustrate the importance of large and key-piece-sized LWD in forming high quality habitat features. Recent recruitment of small and medium size LWD appears incapable of producing the same habitat quality and complexity as seen in those habitats formed by LWD > 50 cm diameter. Pool habitat features associated with small and medium size LWD had essentially the same attributes as free-formed pools independent of LWD (with the exception of percent woody cover).

4.4.1.4 Umbrella Creek Streambed and Substrate Conditions

No recent data are available regarding Umbrella Creek substrate conditions. However, McHenry et al. (1994) sampled substrate conditions in three Umbrella Creek stream reaches (lower, middle, and upper). McHenry et al. (1994) reported the percent fine sediment (>0.85mm) in Umbrella Creek averaged 16.1% (wet-sieve equivalent; actual dry-sieve method equal to 9.1%). Fine sediment levels were uniform between lower, middle, and upper sampling sites. Dlugokenski et al. (1981) sampled Umbrella Creek in 1979 and found that fine sediment in spawning gravel (<0.6mm) ranged from 7% to 25%, averaging ~18%. Dlugokenski et al. (1981) suggest that the "high" levels of fines in spawning gravels are associated with the high road density and lack of adequate road surfacing material. Smith (2000) rated Umbrella Creek "poor" for fine sediment levels in spawning gravel. Current (2006) estimates of road density in Umbrella Creek are high, 7.4 mi/ mi^2 (4.6 km/km^2; Ritchie, unpublished data).

The loss of both quantity and quality of LWD in Umbrella Creek has also likely affected spawning gravel availability, stability, and quality. Significant correlations between the surface area of sediment accumulations and LWD volume have been shown for streams draining old-growth forests in western Washington (Bilby and Ward 1989). Martin (2001) studied streams flowing through old-growth forests in Alaska and found that gravel dominance within habitat units increased with both increased LWD frequency and volume. Bilby and Ward (1991) found that streams draining old-growth forests had larger areas of LWD-associated sediment accumulations than those found in streams draining second-growth forests. Some reaches of Umbrella Creek with low LWD abundance also appear to have coarser sediments (mainly cobble) and a lower frequency of suitable spawning gravels, although no quantitative data have been collected in Umbrella Creek correlating low LWD abundance with decreased quantities of suitable spawning gravel. The marine-sediment geology, moderate gradient, and moderate confinement of most of the Umbrella Creek channel suggests that bedload deposition of gravels and smaller-sized sediments would be expected to occur next to stable wood accumulations.

4.4.1.5 Umbrella Creek Water Quality

Water quality data have been collected in Umbrella Creek intermittently from the mid-1970s to present. Early data collected by Bortleson and Dion (1979) are quite limited for Umbrella Creek. Until recently the most comprehensive water quality dataset had been summarized by Meyer and Brenkman (2001). Meyer and Brenkman (2001) collected water temperature, dissolved oxygen, pH, specific conductivity, and turbidity data monthly from July 21, 1993 through November 30, 1994. Table 4.7 contains a summary of water quality sampling data for Umbrella Creek from Meyer and Brenkman (2001).

Table 4.7. Summary of water quality data collected in Umbrella Creek from July 21, 1993 through November 30, 1994 (source: Meyer and Brenkman 2001).

	Stream Temperature (°C)	**pH**	**Specific Conductivity (uS/cm)**	**Dissolved Oxygen (mg/l)**	**Turbidity (NTU)**
Minimum	2.7	6.2	24.2	8.3	0.3
Maximum	16.0	7.4	100.5	12.3	161.0
Mean	10.0	6.9	59.0	10.2	19.1
Number Months Sampled	n=21	n=16	n=21	n=17	n=20

In recent years additional water quality data have been collected in Umbrella Creek just downstream from the Hoko-Ozette Road Bridge (near the Umbrella Creek stream gage). Makah Fisheries Management began collecting water quality data in Umbrella Creek in January 2004. Data collection is ongoing and is typically collected monthly, but sampling frequency increases to approximately twice per month during spring and summer months. Table 4.8 summarizes the results of water quality sampling by MFM in Umbrella Creek. Water quality conditions measured by MFM are roughly within the same range of conditions measured by Meyer and Brenkman (2001). Some of the minor differences between datasets can be attributed to increased sample frequency during May, June, and July in the MFM dataset.

Table 4.8. Summary of water quality data collected in Umbrella Creek from January 15, 2004 through October 7, 2005 (source: MFM unpublished water quality data).

	Stream Temperature (°C)	**pH**	**Specific Conductivity (uS/cm)**	**Dissolved Oxygen (mg/l)**	**Turbidity (NTU)**
Minimum	5.1	6.1	23.7	8.8	0.0
Maximum	16.3	7.3	90.8	15.2	330.2
Mean	10.1	6.8	59.4	11.6	14.7
Number Sample Points	n=31	n=31	n=31	n=31	n=31

Additional stream temperature monitoring was also conducted using thermographs and data loggers during the summer of 1993 and 1994 near the ONP boundary (MFM unpublished data; Meyer and Brenkman 2001). A review of available temperature data for lower Umbrella Creek indicates that data were collected during nine summers from 1993 through 2005. Stream temperature data from 1998 and 1999 were collected by Green Crow approximately 0.8 mile upstream of the Hoko-Ozette Road Bridge. All other data were collected by MFM at or very near the bridge. Temperature data were collected on a total of 798 days between June 1st and September 30 (1993-2005). Maximum annual temperatures were recorded between July 21 (2003) and August 18 (1994; Table 4.9). The 7-day moving average maximum daily temperatures observed from 1993 through 2005 are depicted in Figure 4.50. Figure 4.51 depicts the number of days sampled and the number of days when water temperature exceeded 16, 18, and 20°C.

Table 4.9. Summary of maximum daily stream temperature observations from lower Umbrella Creek during temperature monitoring from 1993 through 2005 (source: MFM unpublished data, Meyer and Brenkman 2001; Green Crow, unpublished data).

Year	Number of Days Sampled (June 1 to September 30)	Date(s) of Peak Temperature	Peak Temperature (C)	Date of Peak 7-Day Moving Average Daily Maximum Temp.	Peak 7-Day Moving Average Daily Maximum Temperature (C)
1993	72	8/4/1993	21.8	8/6/1993	19.9
1994	107	8/18/1944	19.1	8/18/1944	18.2
1997	36	8/5/1997	18.5	8/10 to 8/16/1997	17.9
1998	64	7/27-28; 8/13/1998	19.4	8/1/1998	18.0
1999	64	8/10/1999	16.3	8/11/9999	15.5
2002	104	07/22/02	19	7/25/2002	17.9
2003	120	7/21/2003	18.7	7/30/2003	17.6
2004	114	7/23/2004	19.8	7/24 to 7/26/2004	18.8
2005	117	7/27/2005	17.6	8/2; 8/4-6/2005	17

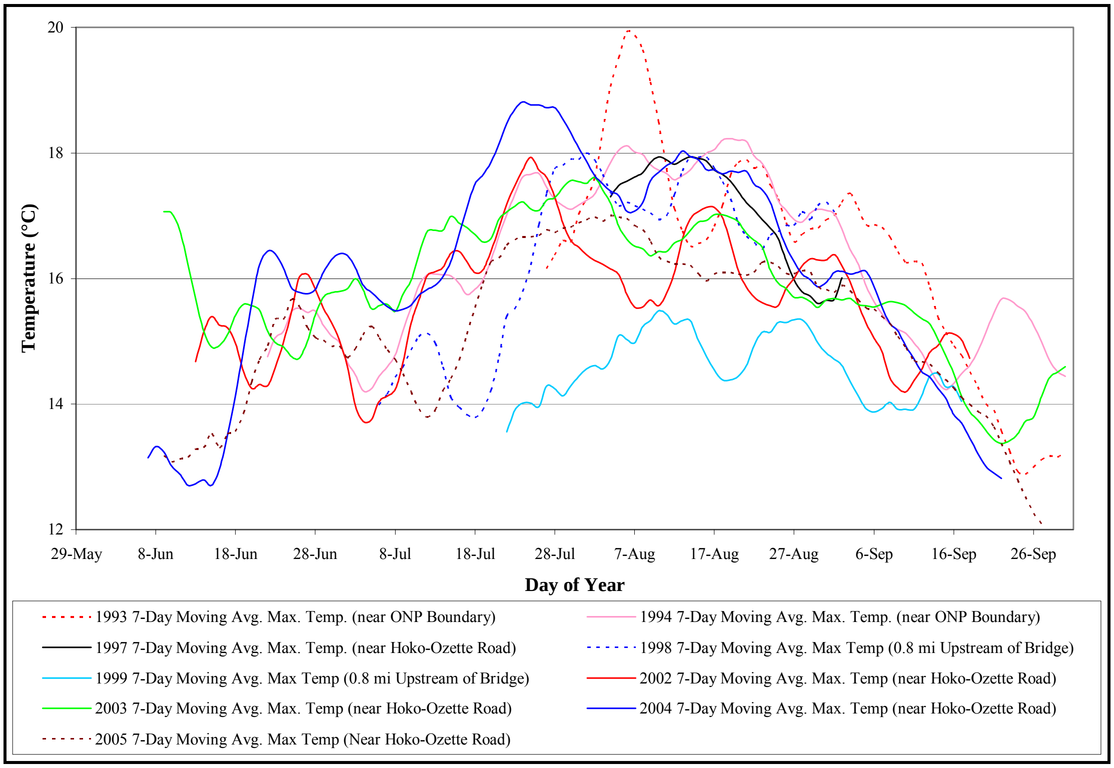

Figure 4.50. Umbrella Creek 7-day moving average maximum stream temperature near Hoko-Ozette Road from 1993-2005 (source: MFM, unpublished stream temperature data; Meyer and Brenkman 2001).

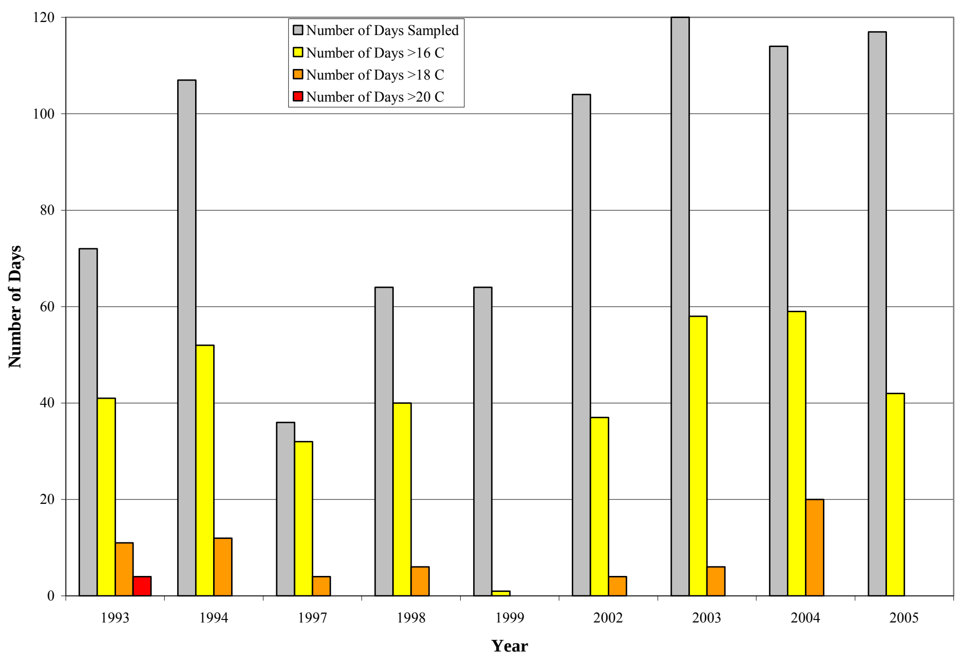

Figure 4.51. Number of days sampled and the number of days stream temperature exceeded 16, 18, and 20 °C in Lower Umbrella Creek (1993-2005) (source: MFM, unpublished stream temperature data; Meyer and Brenkman 2001).

Maximum daily stream temperatures exceeded 16°C on 362 days (45% of the days sampled) between June 1 and September 30 (1993-2005). During the warmest period of summer, July 15 through August 15, data were collected on 267 days. Stream temperatures exceeded 16°C on 203 days (76% of the days sampled). Stream temperatures exceeded 18°C on 51 days (19% of the days sampled). Figure 4.52 includes a summary of the number of days data were collected July 15 through August 15, as well as the number of days when the maximum temperature exceeded 16, 18, and 20°C. The relatively high stream temperatures documented from 1993-2004 are thought to be partially a function of riparian forest disturbance and shade loss (mostly from logging during the last 50 years) and naturally elevated stream temperatures. Kemmerich (1926) reported that the stream temperature in lower Umbrella Creek was 14.5°C on July 1, 1926 and increased each day until it reached 17.8°C on July 12, 1926[14].

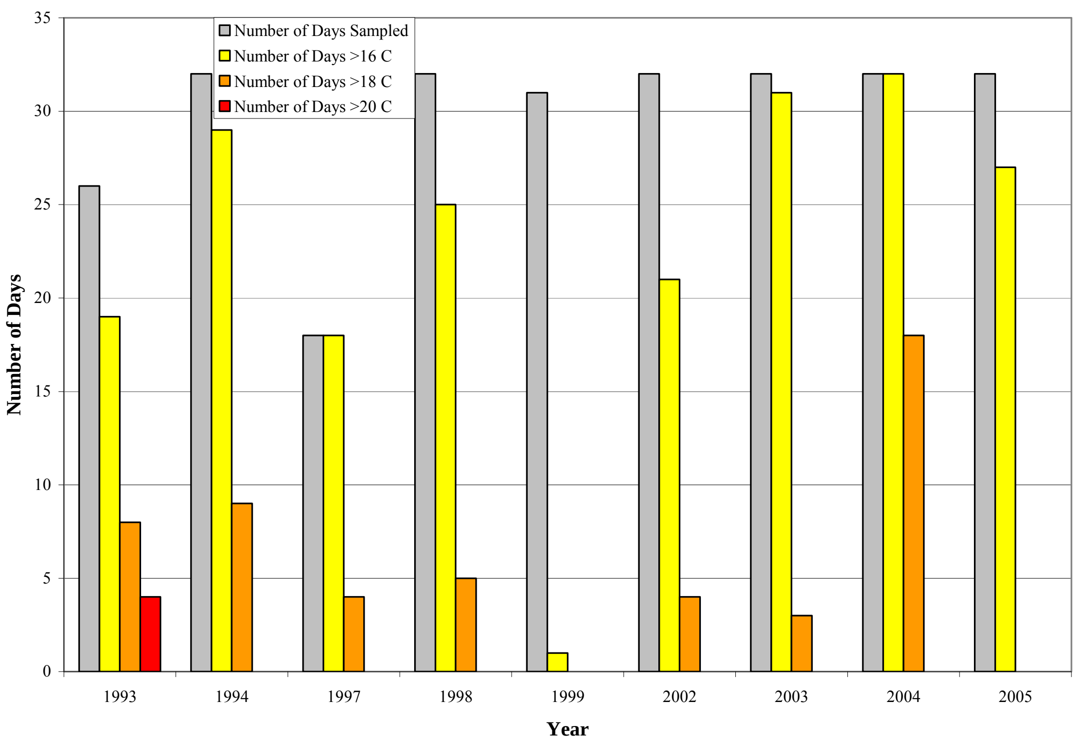

Figure 4.52. Summary of lower Umbrella Creek maximum daily stream temperature data for the period July 15 through August 15 (1993-2004) (source: MFM, unpublished stream temperature data; Meyer and Brenkman 2001).

Other water quality investigators within the watershed have described water quality concerns in addition to stream temperature. Meyer and Brenkman (2001) voiced concern regarding pH, dissolved oxygen, and turbidity levels in Umbrella Creek. They concluded

[14] Kemmerich's observations from 1926 occurred during a period of very low rainfall (4th lowest recorded June-July rainfall in 90 years of record at the Quillayute weather station).

that water quality conditions for fish were marginal. Smith (2000) rated the water quality "poor" for Umbrella Creek based upon stream temperatures consistently exceeding the Washington State Water Quality Standards. Jacobs et al. (1996) suggested that turbidity levels exceeded the threshold at which feeding juvenile salmonids are negatively affected but expressed no concern over the dissolved oxygen, pH, and conductivity levels recorded by in 1993 and 1994 by Meyer and Brenkman (2001)

Makah Fisheries Management installed a continuous submersible turbidity sensor on Umbrella Creek at the County Bridge on 2/17/2005, with the goal of detecting long-term (5-10 plus year) trends in turbidity and SSC. The sensor is deployed down an open-bottom, vertically porous pipe attached to the bridge structure in well-mixed water. The sensor is attached to floats within the pipe, allowing the sensor to adjust vertically with stage changes, assuring the sensor viewing area is off the channel bed during high flows. The sensor (Forest Technology Systems DTS-12 turbidimeter) measures in Nephelometric Turbidity Units (NTU), is factory calibrated annually in Formazin standards of known NTU, has a built-in wiping mechanism to self clean the sensor before every measurement, and measures 100 turbidity samples every 15 minutes and returns the median, mean, minimum, maximum, BES, and variance, in addition to water temperature. Field maintenance consists of periodic equipment checks that consist of cleaning the sensor with soap and water, removing any major debris from the sensor, wiper, boom, or pipe, and flushing the structural components. Point samples of turbidity and SSC are taken periodically at the continuous sensor for correlation purposes and to detect any instrument drift, which is extremely rare

Median turbidity values (15-minute) are plotted in Figure 4.53, along with discharge. In Umbrella Creek turbidity and suspended sediment concentration peaks usually last for less than a day, depending on the length of the flood pulse event. During small discharge events, turbidity rises sharply on the rising limb of the discharge hydrograph and falls more rapidly than discharge on the recession limb. These lower turbidity (and SSC) values on the recession limb at the same discharge (i.e., hysteresis) are a result of the initial flush of readily available sediment from both upland and channel sources (Hicks and Gomez 2003). At these moderate discharges, turbidity and suspended sediment concentrations are dependent on the supply of fine sediment from both upland and channel sources. However, during large flood events in Umbrella Creek, the relationship between discharge and turbidity remains more constant on both the rising and falling limbs of the hydrograph, indicating that for large discharge events, turbidity and SSC are not supply limited, but rather that there is abundant sediment available in the channel network that is limited by transport by available flows (Hicks and Gomez 2003; Nistor and Church 2005).

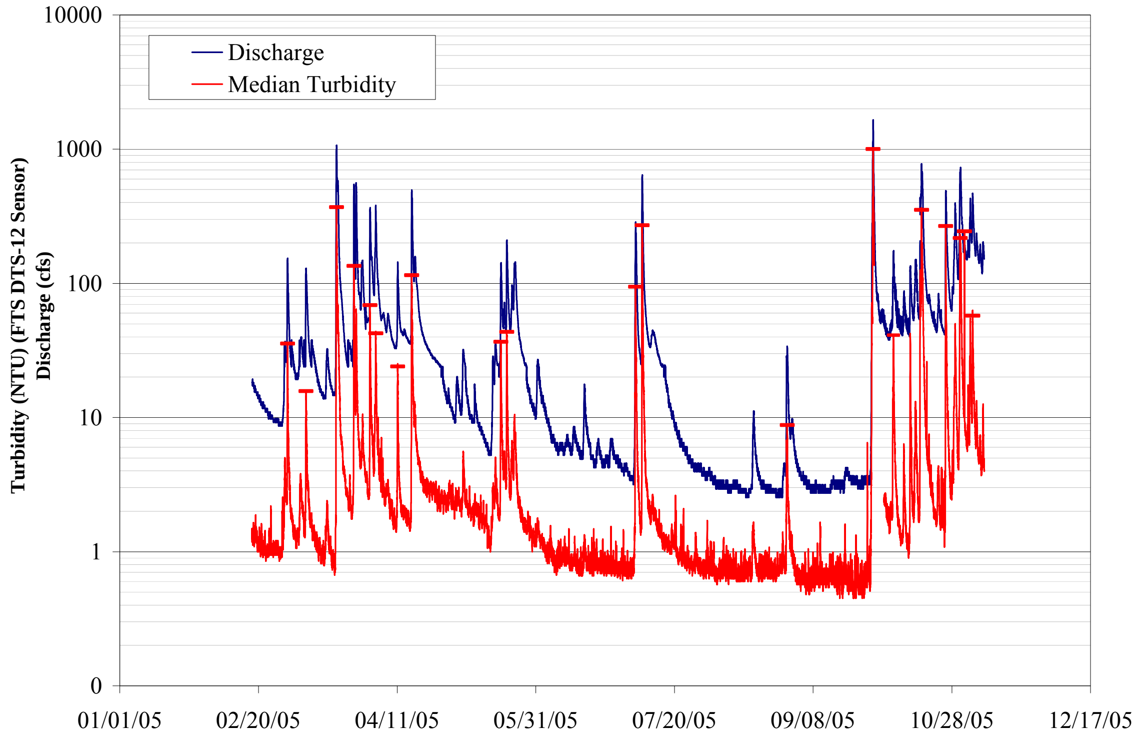

Figure 4.53. Preliminary results from continuous turbidity readings and provisional stream discharge data for Umbrella Creek (source: MFM, unpublished data).

4.4.1.6 Umbrella Creek Hydrology and Streamflow

Makah Fisheries Management installed a continuous stream gage on Umbrella Creek at the Hoko-Ozette Road County Bridge on 12/18/2003 (Figure 4.12). This gage automatically measures and records river stage every 15 minutes. Discharge (ft^3/s-cfs) measurements are periodically taken at this location using current meters and wading rods at low to moderate flows, and current meters and bridgeboard cable equipment at high flows. These discharge data, along with continuous stage data, have been used to create a stage-discharge rating curve or a correlation between stage and discharge. The extreme upper end of the rating curve is defined using standard slope-area measurement techniques (Linsley et al. 1982; Sturm 2001), but still needs further refinement using current meter measurements (i.e., results are provisional).

Instantaneous discharge at Umbrella Creek for water years 2004 and 2005 are plotted in Figure 4.54. In addition to these data, exceedence probabilities (% of time average flow exceeds a given discharge) are displayed that define the 89%, 49%, and 10% exceedence values. These values were calculated by the U.S. Bureau of Reclamation (USBOR) as part of water resource investigations for the Water Resource Inventory Area (WRIA) 20 Watershed Planning Process (Lieb and Perry 2004). Regression equations were developed using monthly total streamflow at Umbrella Creek and monthly total streamflow at the nearby Hoko River gage (USGS 12043300). These synthesized data only represent monthly averaged flows (cubic feet per second) and exceedence of those average flows, but are very useful for defining both the general flow regime (hydrograph magnitude, duration, timing) and variability over time (1962 to 1999). Note that at any given point in time, the instantaneous discharge is much higher or lower than the average monthly flow.

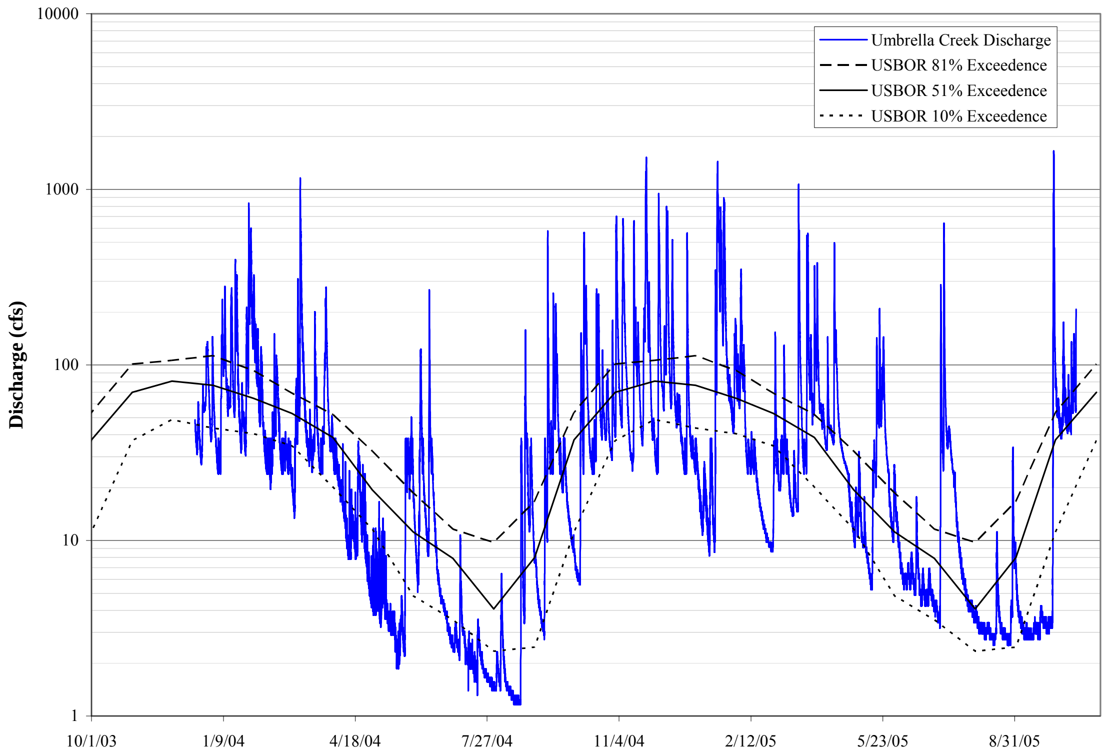

Figure 4.54. Provisional Umbrella Creek discharge data plotted with USBOR synthesized monthly average streamflow exceedence curves (source: MFM, unpublished data; Lieb and Perry 2004).

4.4.2 Big River

Big River is the largest tributary to Lake Ozette. Big River enters the lake along the west side of Swan Bay (Figure 3.16). The Big River watershed drains approximately 22.8 mi^2 (59.1 km^2) and includes several tributaries. The largest tributary is Trout Creek, with a drainage basin area of 5.1mi^2 (13.3 km^2), followed by Dunham (2.1mi^2/13.3 km^2), Solberg (1.4 mi^2/3.7 km^2), Boe (1.1mi^2/2.8 km^2), and Stony creeks (0.8 mi^2/2.1 km^2). The upper mainstem flows to the south-southeast across a relatively wide valley underlain by Pleistocene glacial drift deposits. The northeast side of the valley is bound by topographically steep, Eocene age volcanic flows and breccias (Crescent Formation). The southwest side of the valley is bound by slightly less steep Oligocene-Eocene age marine sedimentary rocks. As the river exits this unique valley it plunges over a set of barrier falls shortly before turning nearly 90 degrees and flowing to the west-southwest. Below the falls, the lower mainstem meanders across a wide (~0.5 mi) gently sloping valley composed of Holocene fluvial deposits and Pleistocene glacial till and drift deposits before entering Lake Ozette.

4.4.2.1 Big River Floodplain Conditions

Big River floodplain conditions and processes have been significantly modified over the last 100 years. Roads and pastures within the floodplain, and to a lesser extent residences, have changed flooding frequency, wood recruitment, channel migration rates, and much of the character of the floodplain. Herrera (2006) reports that 1 to 2 meters of channel incision have occurred during the last 50 years in the lower 11 km (6.8 mi) of Big River. They attribute this channel incision to changes in base level, wood removal, and forest clearing. For the purpose of this report, Big River floodplain impacts have been divided into four categories: changes in base level, road-related impacts, agricultural and residential impacts, and stream clearing and timber harvest impacts. Figure 4.55 depicts Big River channel and floodplain alterations from Swan Bay Road upstream to the 7402 Road Bridge.

4.4.2.1.1 Altered base level related floodplain impacts

Herrera (2006) suggested that much of the observed channel incision in the lower reaches of Lake Ozette tributaries was likely a result of changes in lake level associated with logjam removal from the Ozette River. Herrera (2006) concluded that water surface elevations of Lake Ozette act as a base level control for lake tributaries and that the base level directly affects the channel profile of tributaries. They found that the lower reaches of all lake tributaries investigated were incised upstream of the point at which high lake levels could impose backwater conditions. They made no attempt to differentiate the length of Big River channel incision that was hypothesized to have been caused by changes in base level of Lake Ozette and those thought to be a response to Big River instream wood removal. Where channel incision was thought to have occurred as a result of changes in base level, floodplain connectivity was rated as poor by Herrera (2006).

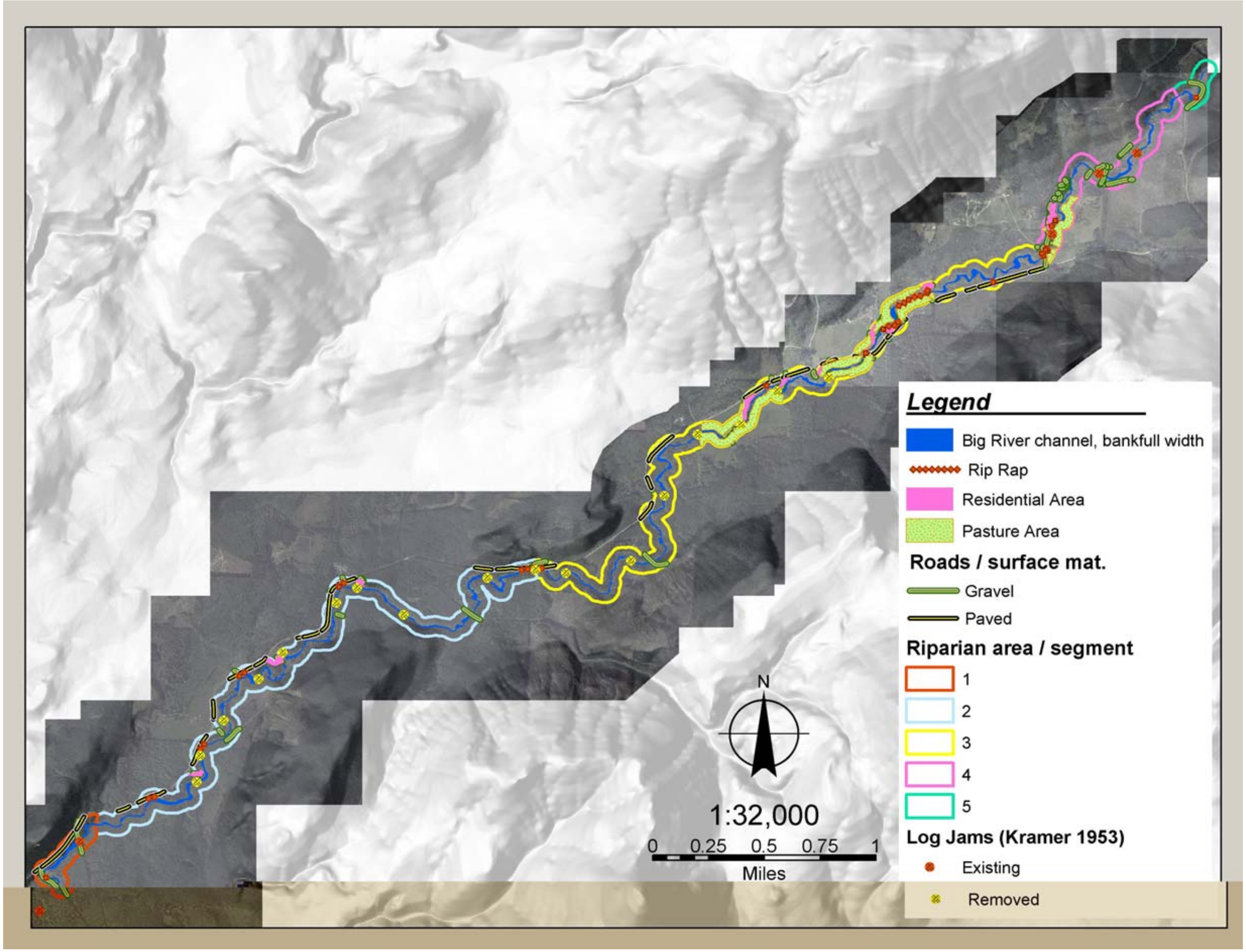

Figure 4.55. Riparian and floodplain alterations within 200 feet of the bankfull edge of Big River (source: channel-segments based on Haggerty and Ritchie 2004; alterations based on 2003 aerial photo review and miscellaneous observations).

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4.4.2.1.2 Road-Related Floodplain Impacts

The Hoko-Ozette Road roughly follows the original wagon trail to Lake Ozette from Clallam Bay. Lake Ozette was described as "*isolated*" by "*an almost impassible road*" in 1923-26 by Kemmerich (1945). The first "road" to Lake Ozette came in 1926 (Jacobs et al. 1996), but it was clearly still plagued with problems. Kramer (1953) noted that in December 1952 the Hoko-Ozette road was at times under water. Road construction, along with repeated "lifts" (which raise the level of the road to prevent flooding) and subsequent bank armoring along the mainstem of Big River, has restricted channel migration, LWD recruitment, and stream-floodplain interactions. Smith (2000) rated floodplain conditions along Big River as poor, based upon the quantity of riparian-adjacent roads.

The bankfull edge of Big River was delineated using georectified aerial photos of the Big River using ArcMap 9.0 (2003 color aerial photos). The zone within 200 feet of the river's bankfull edge was then examined for long-term alterations, such as roads, pastures, residential development, roads, and bank hardening. Road lengths within 200 feet of the river's bankfull edge were calculated for each road segment within each stream segment depicted in Figure 4.55. Total riparian road length based on 2003 aerial photos and 2005 WDNR GIS transportation layer is 6.1 miles. Interestingly, Smith (2000) found that there were 6.1 miles of riparian roads adjacent to the mainstem Big River, but the methods used to make this calculation are unclear. There are 8.8 miles of road per square mile of riparian area within 200 feet of the river's bankfull edge. The highest road densities within 200 feet of the bankfull edge were found in segment 1; where road density averaged 17.8 mi/mi^2 of riparian area (within 200 feet of river; Table 4.10).

Table 4.10. Road lengths within 200 feet of the bankfull edge of Big River and channel segment length.

Channel Segment	Segment Length (Mi.)	Road Length (Mi.)	Miles of Road/ Mile of River	Miles of Road/Sq Mi of Riparian Area
1	0.42	0.66	1.58	17.77
2	3.57	1.66	0.46	6.51
3	3.90	2.97	0.76	10.33
4	1.41	0.83	0.59	8.90

The Hoko-Ozette Road more or less parallels the river from Swan Bay Road (RM 1.55) to the confluence with Boe Creek (RM 9.43), a stream length of 7.9 miles (12.7 km). The Hoko-Ozette Road makes up more than 50% (3.06 miles) of the road length within 200 feet of Big River in segments 1 through 4. Channel segment 3 contains the greatest length of road, but is also the river's longest segment; nonetheless, riparian road density is high (10.3 mi/mi^2 of riparian area). Riprap or other bank hardening features can be found in the banks of Big River in at least 17 locations, preventing the river from migrating across its floodplain and in some cases preventing flood waters from accessing the floodplain. Nearly 4,100 feet of bank armoring structures have been identified along Big River. Several bridge crossings constrict the river and block flood flows from traveling on the floodplain (e.g. Swan Bay Road, 7402 Road).

4.4.2.1.3 Agricultural and Residential Floodplain Impacts

Agricultural development along the floodplain of Big River began in the late 19th century. Pioneer families worked for years to clear virgin forest into workable pasture. Kramer (1953) noted that erosion was evident along stream reaches in lower Big River that had been cleared for agricultural purposes. An inventory of riparian-adjacent pastures visible on color aerial photos (2003 flight) indicates that the majority of pasture land and residences occur within segments 2 through 4 (Trout Creek to just downstream of the Boe Family Bridge). Pasture and residential areas adjacent to the river within 200 feet of the bankfull edge were delineated and area and length by segments are reported in Table 4.11.

Table 4.11. Summary of Big River pasture and residential development within 200 feet of the bankfull edge.

Channel Segment ID	Segment Length (Miles)	Riparian Area Acres (within 200 ft of BF)	Pasture Area Acres	Residential Area Acres	Pasture and Residential Area as a Percentage of Total Riparian Area	Percent of River Length with Pastures or Residences within 200 Feet of BF Edge
1	0.42	23.8	na	na	0.0%	0.0%
2	3.57	162.7	1.5	1.5	1.8%	5.4%
3	3.90	184.0	20.2	3.9	13.1%	35.9%
4	1.41	59.3	6.6	2.2	14.8%	19.9%

Floodplain and riparian encroachment by pastures and residences was highest in segments 3 and 4, where 13 to 15% of the riparian area within 200 feet of Big River has been converted from forest to pasture or residential use. Approximately 20% of the length of the river between segment 1 and 4 has pastures or residences within 200 feet of the bankfull edge. Many but not all of the lowest quality habitat segments (based on pool quality and LWD abundance) in Big River were located adjacent to pastures and/or residences. Lack of shade and forested riparian habitat along these reaches can raise stream temperatures, reduce bank stability, increase sedimentation and bank erosion rates, and delay or prevent habitat from recovering to pre-disturbance conditions.

Figure 4.56 displays three aerial photos from 1994, 2000, and 2003 along a bend of Big River just upstream of the Hoko-Ozette Road. This section of Big River historically was affected by in-channel wood removal, riparian logging and clearing, channelization, and bank protection using old cars and rock. Big River responded to these changes by going through a series of channel evolution stages (Cederholm and Koski 1977; Simon and Hupp 1992; Simon 1995; Herrera 2006). First, the channel incised (degraded) due to confined banks and lack of bed roughness. Channelized reaches confined flood flows and accelerated velocities, aided by lack of LWD roughness. Channel incision was then followed by bank instability and the collapse of over-steepened banks. Bank failure was partially mitigated by bank armoring (cars and rock), but these measures were only effective locally where significant armor maintenance occurred (i.e., County road). Sediment that eroded from bank failure, channel incision, and other upland sources was transported downstream toward the bend in Figure 4.56, causing local channel aggradation. This aggradation, along with the lack of a functional riparian corridor and accelerated velocities from upstream channelized reaches, further accelerated bank erosion, which can be observed between 1994 and 2003. Over time, this section of Big River may again reach an equilibrium width, depth, roughness, and sediment transport capacity, but only after significant channel change (Simon and Hupp 1992; Simon 1995; Herrera 2006). Other sections of Big River both up and downstream of these photos show similar signs of channel evolution. However, these other reaches display earlier stages of channel evolution such as incision and bank collapse, which indicate the likelihood of significant future changes in channel stability.

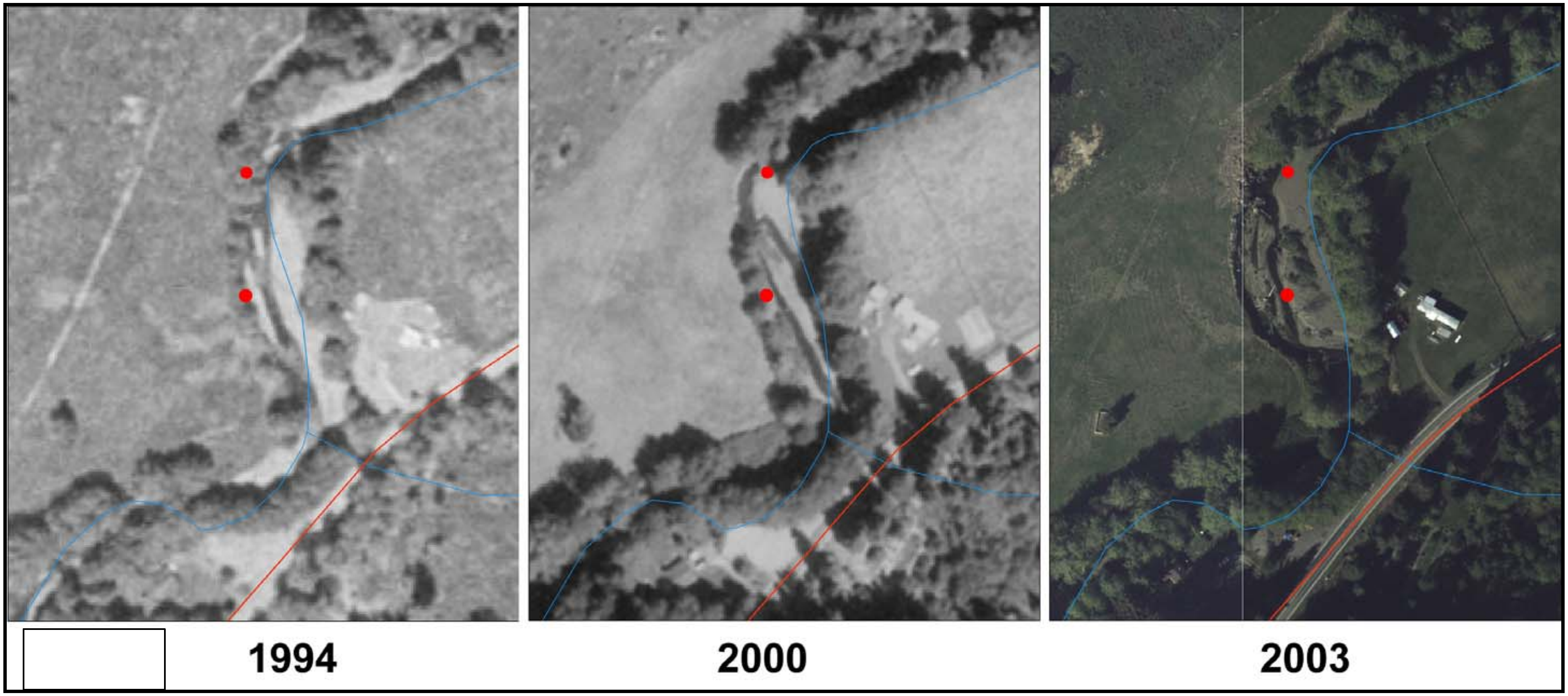

Figure 4.56. Nine-year photo history of Big River just upstream of the Hoko-Ozette Road bridge near confluence with Stony Creek. Photos illustrate progressive bank erosion and channel widening. (Note: Red dots are in the same position in each photo for reference.)

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4.4.2.1.4 Stream Clearing and Forestry Related Floodplain Impacts

Floodplain conditions and processes are believed to have been altered by LWD removal operations. Kramer (1953) describes clearing 3.5 miles of the river of logs and debris between approximately RM 2 and RM 6. The effects of LWD removal on river-floodplain interactions during this period are not well documented, but Smith (2000) cites channel incision as another floodplain problem in the watershed. Past clear-cut timber harvesting adjacent to Big River has resulted in degraded riparian conditions for most of the river's length. Wood removal, insufficient LWD recruitment, and channel incision have reduced floodplain connectivity in Big River throughout most of the stream length in segments 1 through 4.

4.4.2.2 Big River Riparian Conditions

Riparian conditions in Big River have been highly modified during the last 100 years. Along the mainstem of Big River nearly all (>95%) of the old growth riparian forest has been clear-cut once or converted to pasture land. Meyer and Brenkman (2001) reported that 84% of forest within the Big River watershed was 40 years old or less. Less than 1% of the forest within the watershed was classified as >80 years old (Meyer and Brenkman 2001). Smith (2000) rated the riparian conditions along Big River as poor to fair. However, the data used by Smith (2000) were limited to only a fraction of the river's length. Roads and/or pastures occupy miles of the river's historical riparian forests. Orthophotos taken in the summer of 2000 show that while the majority of riparian forests have been converted to stands dominated by red alder, some residual large conifer trees are still present scattered in small patches, as are some fairly continuous stream reaches dominated by stands of young- to medium-age conifers. Prior to timber harvest, riparian stands were composed of Sitka spruce, western hemlock, and western red cedar. Riparian stands in many of the primary tributaries to Big River are also degraded from pre-disturbance condition. Extensive stands of young to medium-aged red alders dominate the riparian forest along many of the tributaries.

Disturbed stream banks in many portions of Big River are infested with reed canary grass (*Phalaris arundinacea*) that has altered channel and floodplain interactions. Japanese knotweed (*Polygonum cuspidatum*) and Giant knotweed (*Polygonum sachalinense*) are rapidly colonizing portions of the lower mainstem (Figure 4.57. These non-native invasive plants are competing with native riparian plant colonization of stream banks and floodplains, which can alter floodplain and channel migration dynamics (e.g., floodplain roughness and sediment filtering efficiency; bank stability and erosion rates; and future LWD recruitment).

Figure 4.57. Photo depicting knotweed colonization along the mainstem Big River (source: photo from Clallam County Noxious Weed Control Board 2005).

4.4.2.3 Big River Pool and LWD Habitat Conditions

Pool and LWD habitat data were collected by the Makah Tribe during the summer of 1999 and are summarized in detail by Haggerty and Ritchie (2004). Field data were collected for almost 17,000 meters of channel within the mainstem of Big River and 16,000 meters in tributaries. Channel attribute data for Lake Ozette tributaries can be found in Appendix D. LWD and habitat data were collected in 33 habitat segments encompassing the 17,221 meters of channel in the mainstem (from the Swan Bay Road to the anadromous barrier). A total of 6,756 pieces of LWD were inventoried, of which 69%, 24%, and 7% were categorized as conifer, deciduous, and unknown respectively. Only slightly more than 1% of the pieces inventoried were classified as key pieces. Approximately 75% of the pieces inventoried were <50cm in diameter. Haggerty and Ritchie (2004) developed a habitat and LWD rating system to evaluate habitat and LWD conditions within the watershed. The results are included in Appendix E. Figure 4.58 depicts the frequency of LWD > 50 cm diameter and total LWD piece frequency per 100 meters for each habitat segment in the Big River watershed.

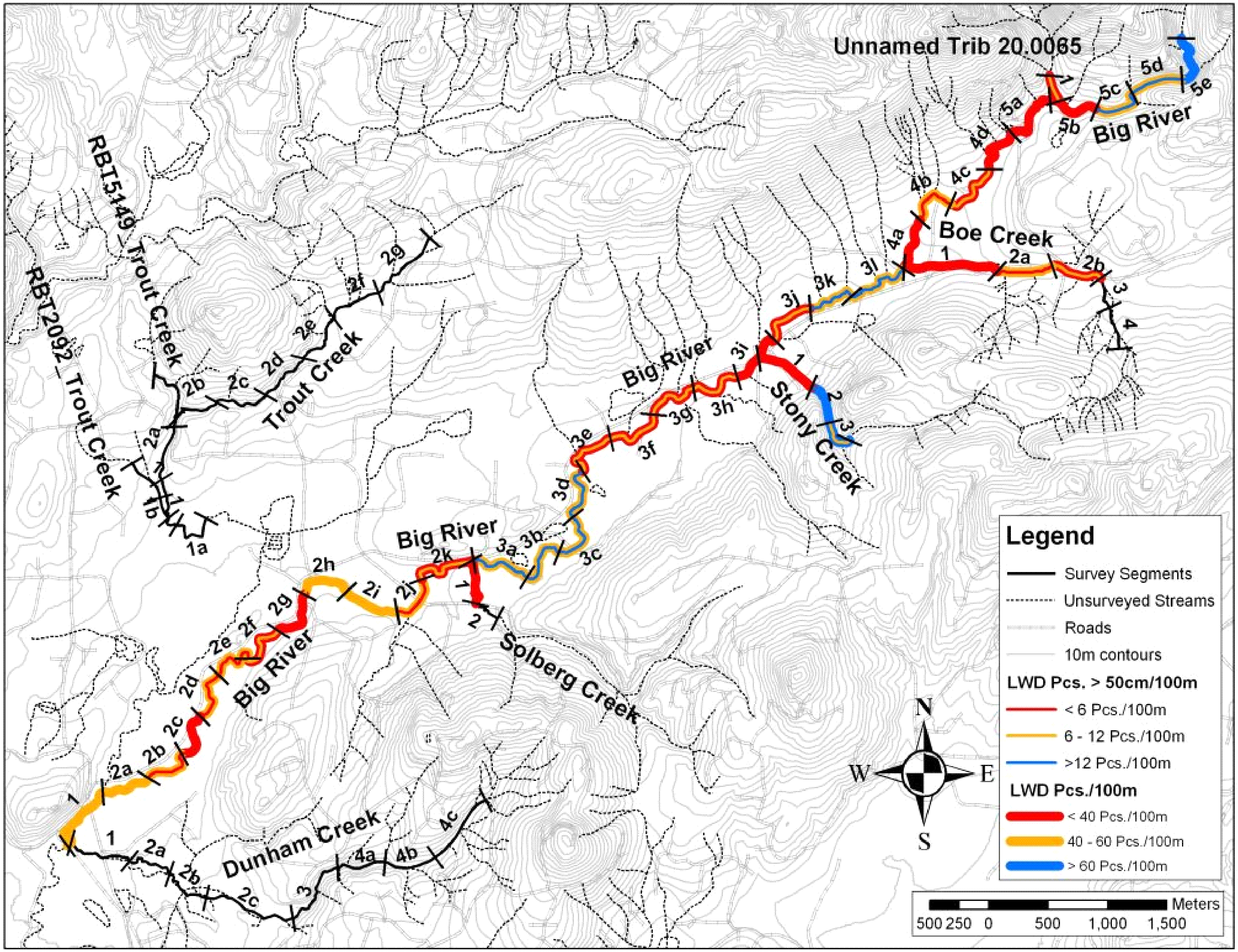

Figure 4.58. Big River watershed LWD >50cm diameter and total LWD piece count per 100 meters calculated for each habitat segment inventoried (source: Haggerty and Ritchie 2004).

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Pool habitat conditions were evaluated for the same habitat segments mentioned above. A total of 399 pools were inventoried in the mainstem of Big River. The average maximum pool depth was 1.03 meters and average pool length was 29 meters. Typically the best pool habitats were associated with LWD (Haggerty and Ritchie 2004). Haggerty and Ritchie (2004) found that on average pools formed by the largest LWD were the deepest, longest, and most complex (Table 4.12). Pools formed by key-piece-sized LWD had an average maximum pool depth nearly 1.5 times greater than pools formed by LWD < 50cm diameter. Haggerty and Ritchie (2004) rated several pool habitat condition variables including pool frequency, percent pools (by length), average maximum and residual pool depth, average pool length, pools >1m deep/km, pool cover, and percent of pools formed by LWD. Figure 4.59 depicts pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in the Big River watershed.

Table 4.12. Big River Pool Attributes Grouped by Primary Pool Forming Agent (source: Haggerty and Ritchie 2004).

Pool Forming Agent	Number of Pools	Avg Max Pool Depth	Avg Res. Pool Depth	Avg Pool Length	Avg No. of Pieces of LWD Forming Pools	0-5% Woody Cover in Pool	6-20% Woody Cover in Pool	>20% Woody Cover in Pool
Key LWD	37	1.31	1.08	41.7	5.1	36%	28%	36%
L+ LWD	94	1.11	0.93	32.0	3.8	57%	30%	13%
L/L- LWD	83	1.14	0.90	31.4	3.3	49%	38%	13%
Medium LWD	63	0.92	0.70	22.6	2.1	53%	31%	16%
Small LWD	2	0.81	0.58	15.45	2.0	50%	50%	0%
Free-formed	98	0.86	0.70	22.5	0.0	86%	13%	1%
Free-formed w/LWD	19	0.96	0.79	33.8	1.4	74%	16%	11%

Riparian forest alterations including bank armoring, channelization, agricultural development, riparian logging, and invasive non-native vegetation have decreased the near- and long-term LWD recruitment potential along almost the entire length of Big River. Stream reaches with the lowest LWD piece counts and poorest pool quality habitat were most often adjacent to the most significantly impacted riparian and floodplain areas. In-stream LWD removal and decreased recruitment are likely responsible for the degraded LWD conditions observed in Big River. The low gradient nature of Big River appears capable of developing free-formed pools independent of LWD. However, the habitat and LWD data summarized by Haggerty and Ritchie (2004) illustrate the importance of large and key-piece-sized LWD in forming high quality habitat features. Recent recruitment of small and medium size LWD appears incapable of producing the same habitat complexity as seen in those habitats formed by LWD > 50 cm diameter.

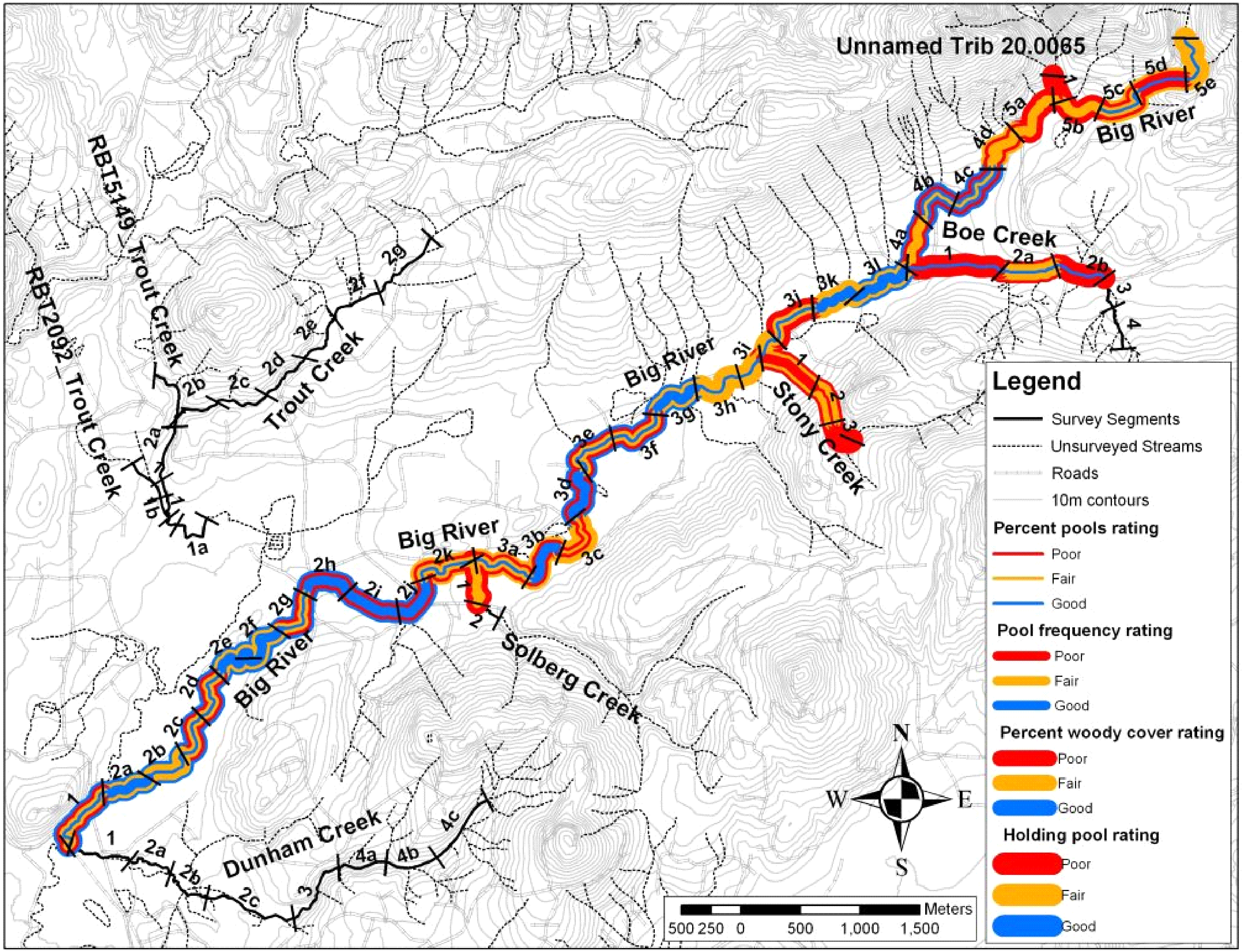

Figure 4.59. Pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in the Big River watershed (source: Haggerty and Ritchie 2004).

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4.4.2.4 Big River Streambed and Substrate Conditions

Limited data are available regarding Big River substrate conditions. Kramer (1953) described the Big River as having almost a continuous bed of gravel from the Hoko-Ozette Road Bridge to about a mile from the mouth. Bortleson and Dion (1979) reported that Big River contained approximately 351,000 ft^2 ($32,600m^2$) of spawnable habitat in the mainstem. McHenry et al. (1994) sampled substrate conditions in two Big River stream reaches, segment 2h (Figure 4.58) and segment 5b. McHenry et al. (1994) reported the percent fine sediment (>0.85mm) in spawning gravels for the lower sample site of 15.7% (wet-sieve equivalent; dry-sieve method equal to 9.5%) and 17.3% (wet-sieve equivalent; dry-sieve method equal to 8.5%) in the upper site. Martin Environmental (1999) rated spawning conditions good in all segments surveyed (2.5 miles [4.1 km] of channel) in 1998, based upon the quantity of spawnable habitat in riffles and pool tail-outs. Smith (2000) rated fine sediment levels in spawning gravels "poor" in Big River.

The current (2006) estimated road density for the Big River watershed is 6.4 mi/mi^2 (4.0 km/km^2; Ritchie, unpublished data). High road densities in the Big River watershed likely contribute to the high levels of fine sediment observed in spawning gravel. Debris flows in the upper watershed are also a source of both coarse and fine sediment. Herrera (2006) described the upper reaches of Big River as appearing to be overwhelmed by coarse sediment inputs. They found that portions of river flowed exclusively through subsurface sediments in the channel at low flow (these areas correspond to segments 3i, 3j, and 4a in Figure 4.58).

4.4.2.5 Big River Water Quality

Water quality data have been collected intermittently in Big River since the mid-1970s to present. Early data collected by Bortleson and Dion (1979) are very limited for Big River. Until recently the most comprehensive water quality dataset was summarized by Meyer and Brenkman (2001). Meyer and Brenkman (2001) collected water temperature, dissolved oxygen, pH, specific conductivity, and turbidity data monthly from July 21, 1993 through November 30, 1994. Table 4.13 contains a summary of water quality sampling data for Big River from Meyer and Brenkman (2001).

Table 4.13. Summary of water quality data collected in Big River from July 21, 1993 through November 30, 1994 (source: Meyer and Brenkman 2001).

	Stream Temperature (°C)	**pH**	**Specific Conductivity (uS/cm)**	**Dissolved Oxygen (mg/l)**	**Turbidity (NTU)**
Minimum	3.5	6.0	22.6	7.3	0.7
Maximum	16.8	7.1	70.0	11.6	185.0
Mean	10.0	6.7	49.0	9.7	23.7
Number Months Sampled	n=21	n=16	n=21	n=17	n=15

In recent years, additional water quality data have been collected near the confluences of Boe, Solberg, and Trout creeks in Big River. Makah Fisheries Management began collecting water quality data in Big River in January 2004. Data collection is ongoing and is typically collected monthly, but sampling frequency increases to approximately twice per month during spring and summer months Table 4.14 summarizes the results of water quality sampling by MFM in Big River. Water quality conditions measured by MFM are roughly within the same range of conditions measured by Meyer and Brenkman (2001). Some of the minor differences between datasets can be attributed to increased sample frequency during May, June, and July in the MFM dataset.

Table 4.14. Summary of water quality data collected from three sites in Big River from January 15, 2004 through October 7, 2005 (source: MFM, unpublished data).

		Stream Temperature (°C)	pH	Specific Conductivity (uS/cm)	Dissolved Oxygen (mg/l)	Turbidity (NTU)
Big River Below Trout Creek	Minimum	5	5.9	29.4	8.5	0
	Maximum	15.9	7.2	61.1	16	177
	Mean	10.2	6.7	50.3	11.3	12
	Number of Days Sampled	n=30	n=30	n=30	n=30	n=30
Big River Above Solberg Creek	Minimum	5.4	6.2	0	9.1	0
	Maximum	15.4	7.3	60	16.1	61.6
	Mean	10.3	6.8	49.3	11.6	3.5
	Number of Days Sampled	n=31	n=31	n=30	n=30	n=31
Big River Above Boe Creek	Minimum	5.3	6.6	0	8.5	1
	Maximum	16.5	7.3	59.3	20.4	13
	Mean	10.4	7	46.6	11.8	1.5
	Number of Days Sampled	n=31	n=31	n=30	n=30	n=31

Additional stream temperature monitoring was also conducted using a thermograph and data logger during the summer of 1993 (Meyer and Brenkman 2001). However, the thermograph became exposed, rendering summertime temperature data invalid for Big River (Meyer and Brenkman 2001). Klinge (1991) also investigated stream temperatures in Big River. During the summer of 1990, daily stream temperatures averaged > 16°C for 37 days between July 6 and August 17 (Klinge 1991). The peak temperature recorded was 18.3°C (Klinge 1991). Additional stream temperature data were also collected in Big River during the following years: 1997, 2002, 2003, and 2004. Figure 4.60 illustrates daily maximum and 7-day moving daily average maximum stream temperature for the lower Big River (RM 1.7- near Trout Creek) during the summers of 1997 and 2004. Stream temperatures exceeded 16°C on 25 and 52 days during monitoring in 1997 and 2004 respectively. Temperatures exceeding 18°C were recorded on 18 days in 2004 and none in 1997 (MFM unpublished stream temperature data).

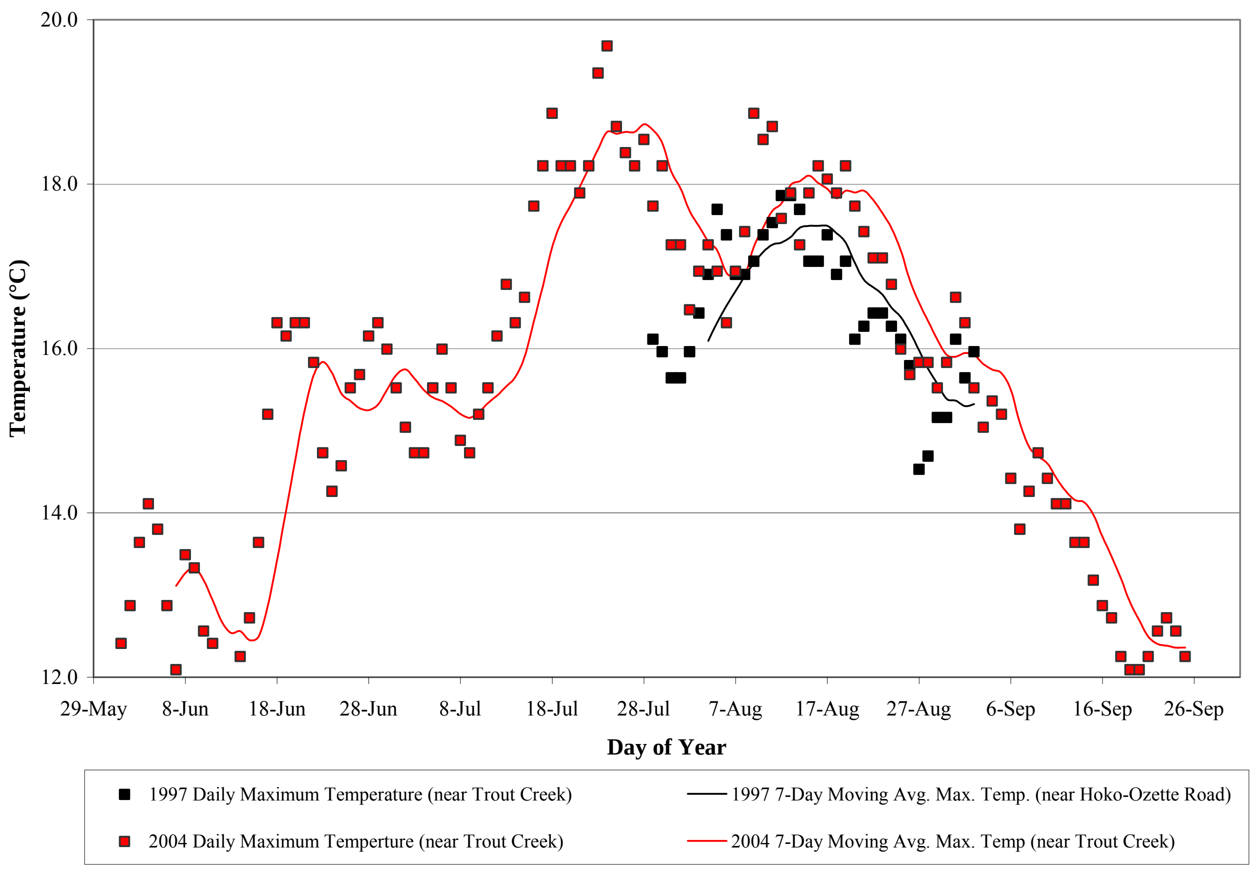

Figure 4.60. Big River daily maximum and 7-day moving average maximum stream temperature near Trout Creek during the summers of 1997 and 2004 (source: MFM, unpublished stream temperature data).

Temperature data were collected at sites near Solberg Creek and near Boe Creek during the summers of 2002 and 2003. However, the thermograph deployed near Boe Creek malfunctioned so there is no data available for upstream/downstream temperature comparisons in 2003. Figure 4.61 illustrates daily maximum and 7-day moving daily average maximum stream temperature for Big River at RM 4.8 and RM 8.1 during the summer of 2002. Stream temperatures exceeded 16°C on 9 days at RM 4.8 (near Solberg Creek) and 34 days at RM 8.1 (near Boe Creek). Temperatures exceeding 18°C were recorded on 2 days in 2002 and only at the site near Boe Creek (MFM unpublished stream temperature data). In 2003 stream temperatures at RM 4.8 exceeded 16°C on 22 days, but never exceeded 18°C (peak temp 17.9°C).

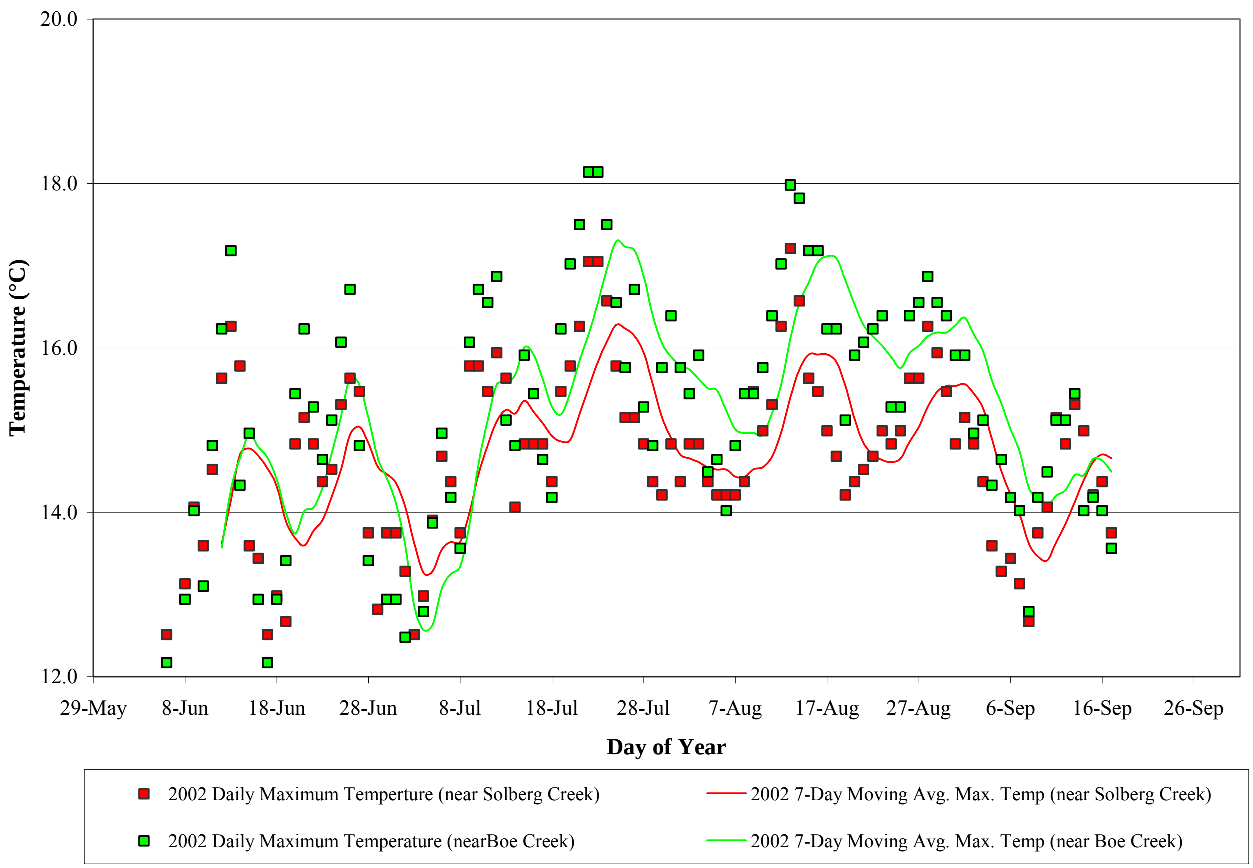

Figure 4.61. Big River daily maximum and 7-day moving average maximum stream temperature near Solberg and Trout creeks during the summer of 2002 (source: MFM, unpublished stream temperature data).

In addition to stream temperature data, the Makah Tribe has collected bacteria data (fecal coliform) in Big River from 2002 to present. Water was collected on a total of 16 days for the site near Solberg Creek, 11 days near the site near Trout Creek, and 9 days for the site near Boe Creek. All but one of the samples collected at Solberg Creek contained higher bacteria concentrations than samples collected near Boe Creek (Figure 4.62). The limited data suggests that there is a source of bacteria entering Big River between Boe and Solberg Creek. These data further suggest that Big River does not comply with Washington State Water Quality Standards within the reach between Boe Creek and Solberg Creek (greater than 10% of samples exceed 100 colonies per 100 ml). Sites upstream and downstream of Solberg Creek appear to comply with water quality standards, since the geometric mean of all samples is less than 50 and not more than 10% of samples exceed 50 colonies/100ml.

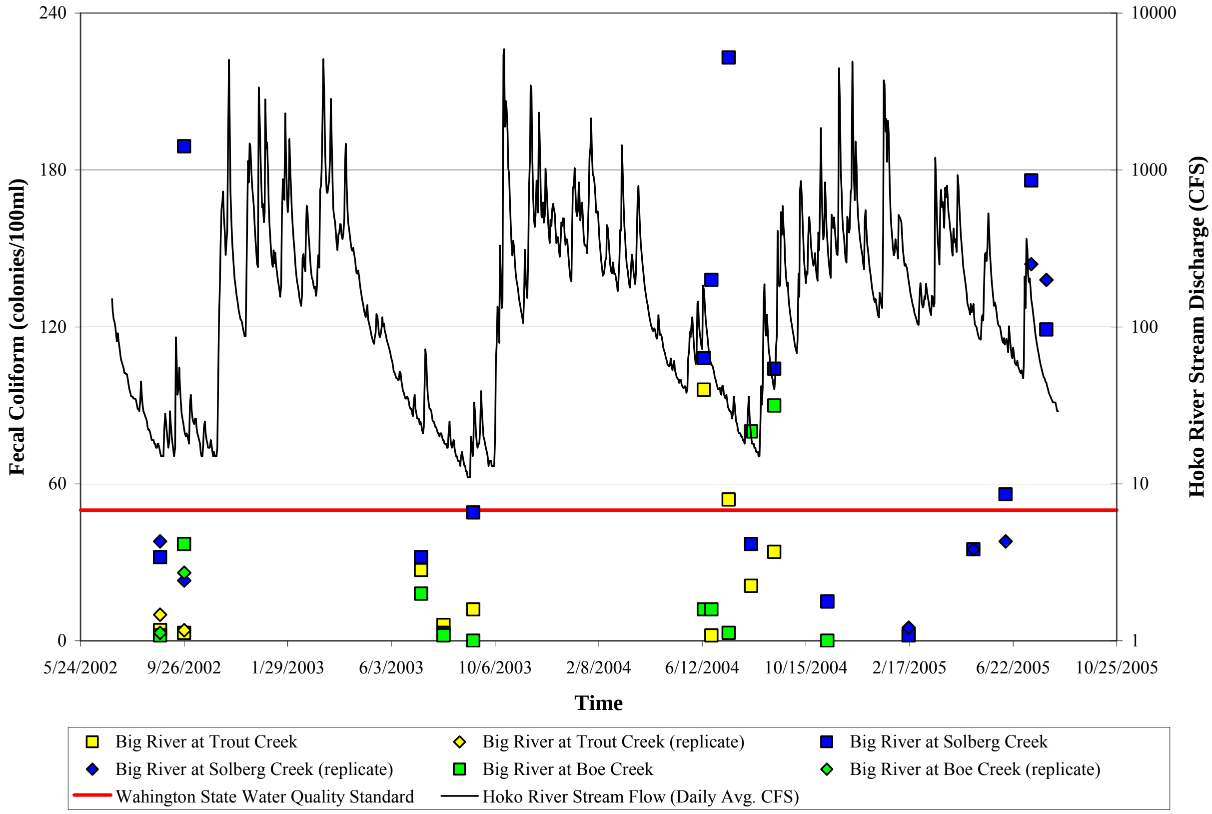

Figure 4.62. Fecal coliform concentrations from three sites along Big River from 2002 to 2005, contrasted with Hoko River streamflow data and Washington State Water Quality Standards (source: USGS streamflow data; MFM, unpublished water quality data).

Meyer and Brenkman (2001) expressed additional concern regarding pH, dissolved oxygen, and turbidity levels in Big River. Extremely high turbidities of 185 NTUs were recorded by Meyer and Brenkman (2001). They concluded that water quality conditions for fish were marginal in Big River. Smith (2000) rated the water quality “poor” for Big River based upon stream temperatures consistently exceeding the Washington State Water Quality Standards. Jacobs et al. (1996) suggested that turbidity levels exceeded the threshold at which feeding juvenile salmonids are negatively impacted but voiced no concern over the dissolved oxygen, pH, and conductivity levels recorded by Meyer and Brenkman (2001). Timber harvest and log haul during the wet season often contribute to the high turbidity levels observed during rainfall events.

Makah Fisheries Management installed a continuous submersible turbidity sensor on Big River on State Land on 2/8/2005, with the goal of detecting long-term (5-10 plus year) trends in turbidity and suspended sediment concentration. The sensor is deployed down an open-bottom, vertically porous pipe attached to the bridge structure in well mixed water. The sensor is attached to floats within the pipe, allowing the sensor to adjust vertically with stage changes, assuring the sensor viewing area is off the channel bed during high flows. The sensor (Forest Technology Systems DTS-12 turbidimeter) measures in Nephelometric Turbidity Units (NTU), is factory calibrated annually in Formazin standards of known NTU, has a built-in wiping mechanism to self clean the sensor before every measurement, and measures 100 turbidity samples every 15 minutes and returns the median, mean, minimum, maximum, BES, and variance, in addition to water temperature. Field maintenance consists of periodic equipment checks that consist of cleaning the sensor with soap and water, removing any major debris from the sensor, wiper, boom, or pipe, and flushing the structural components.

Median turbidity values (15-minute) are plotted in Figure 4.63, along with discharge. Turbidity (and SSC) peaks in Big River usually last for less than a day, depending on the length of the flood pulse event. During small discharge events, turbidity rises sharply on the rising limb of the discharge hydrograph, but then falls more rapidly than discharge on the falling limb of the hydrograph. This is even more evident in Figure 4.64 for a summer storm in Big River, where the turbidity peak precedes the discharge peak and then recedes at a higher rate than discharge. These lower turbidity (and SSC) values on the recession limb at the same discharge (i.e., hysteresis) are a result of the initial flush of readily available sediment from both upland and channel sources (Hicks and Gomez 2003). Thus, for most common discharge events, turbidity and suspended sediment concentrations are dependent on the supply of fine sediment from both upland and channel sources.

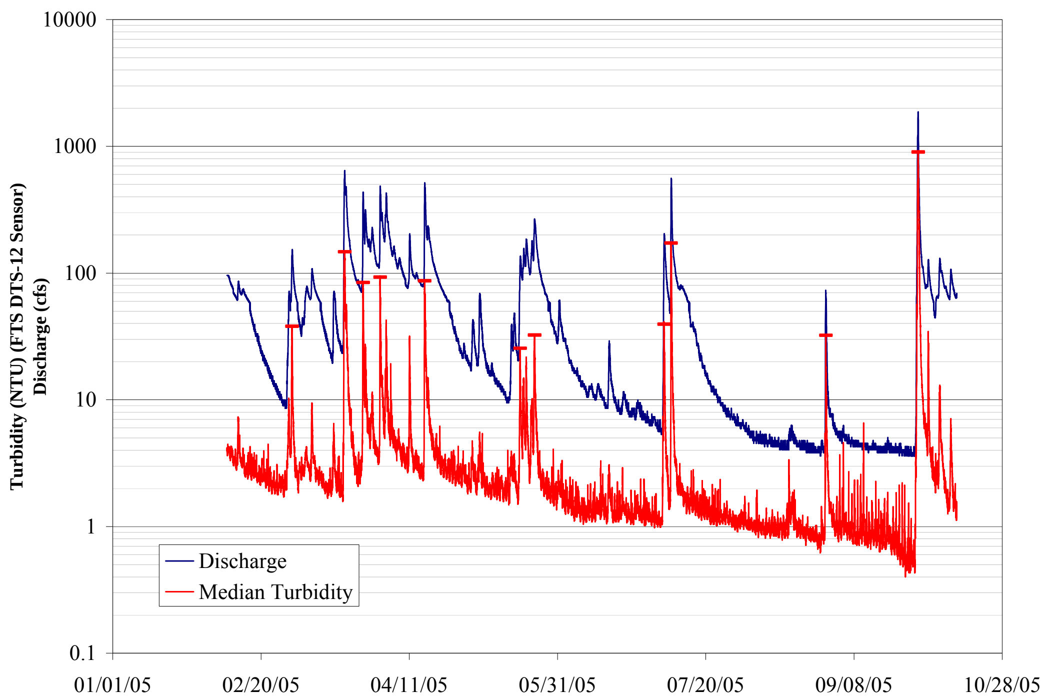

Figure 4.63. Preliminary results from continuous turbidity readings and provisional stream discharge data for Big River (source: MFM, unpublished data).

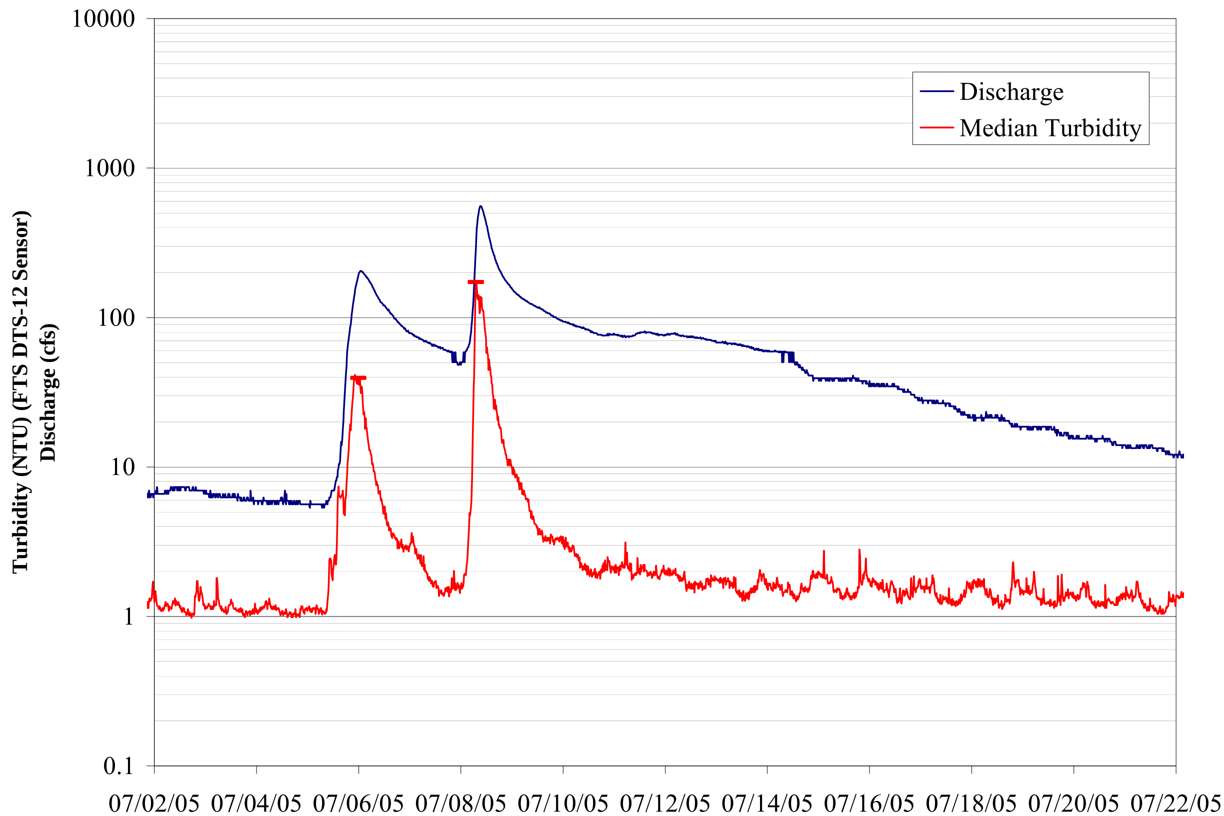

Figure 4.64. Big River turbidity and discharge data for July 2005 storm events (source: MFM, unpublished data).

However, the relationship between turbidity (and SSC) and discharge varies between storm events, as can the degree that hysteresis loops are present in the relationship. A single relationship (or curve) between turbidity (or SSC) and discharge during a single storm event indicates an unlimited sediment supply with transport dependent on available flow energy. Clockwise hysteresis loops in the turbidity (or SSC) and discharge relationship indicates a depletion of the sediment supply during an event, with wider loops indicating degree of depletion (Nistor and Church 2005). As observed in most of the tributary storm event data (to date) in the Ozette watershed, turbidity (and SSC) are dependent on the supply of fine sediment, as indicated by the dominance of clockwise hysteresis loops (Figure 4.65). However, during the few larger discharge events measured in Big River, Umbrella Creek and Coal Creek, the turbidity (or SSC) and discharge relationships display largely one single relationship, indicating that at relatively high discharges there is an unlimited supply of fine sediment within these stream reaches and a breakdown of supply limitation (Figure 4.65).

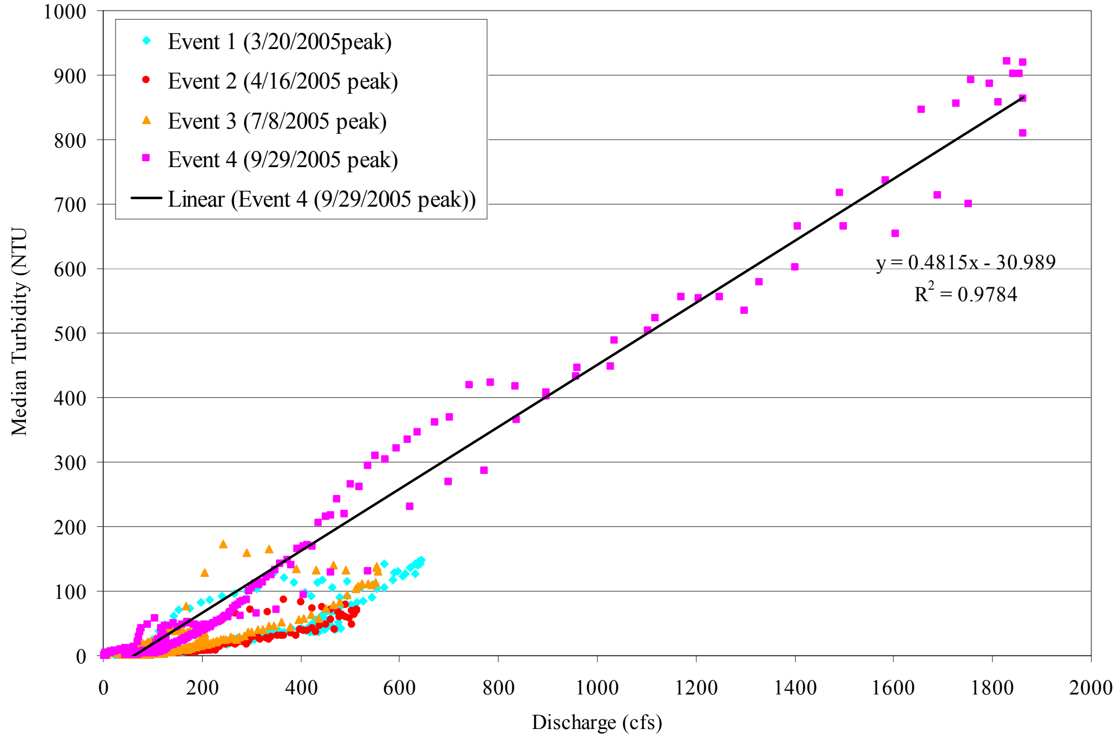

Figure 4.65. Relationship between discharge and median turbidity during four Big River storm events (source: MFM, unpublished data).

Few spatial water quality data are available for the Big River watershed, including turbidity. Three water quality sampling sites exist on Big River, oriented longitudinally along the mainstem. During a relative small discharge event on 2/4/05, turbidity measurements were taken approximately every hour at these three sites during the rising and falling limbs of the hydrograph (Figure 4.66). Measurements were made using a calibrated Hydro Lab water quality multi-probe. Peak turbidities were lowest near the upstream end of the Big River alluvial valley and increased in the downstream direction. This pattern of increasing turbidity in the downstream direction could be a result of increasing turbidity (or SSC) input between these sampling points from tributary sources (washload) or from re-suspension of the finer fraction of bed material deposited locally. While both sources are likely responsible for this longitudinal increase in turbidity, the lower end of Big River has evolved into a fine sediment aggrading reach dominated by silt and sand deposition from local and upstream sources, following initial gravel bed conditions in the 1950s (Kramer 1953) and channel incision for several decades after the 1950s (Herrera 2006).

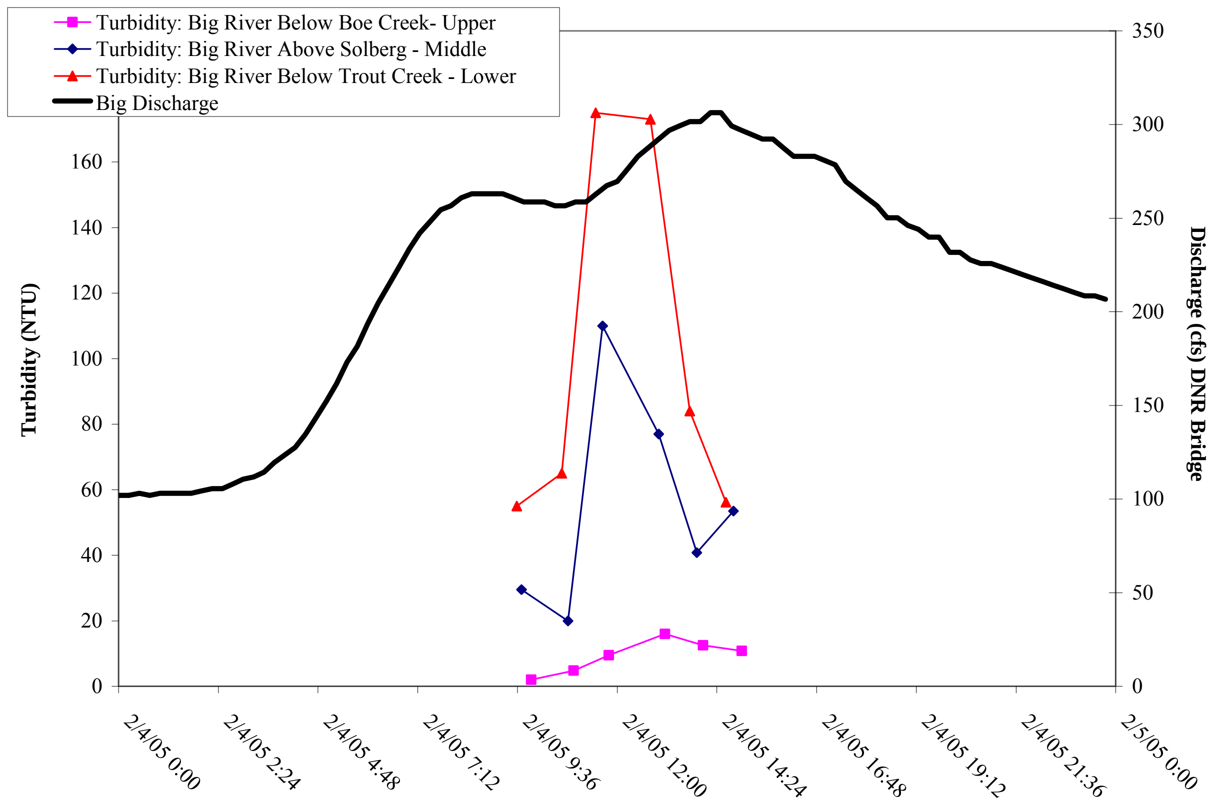

Figure 4.66. Longitudinal changes in turbidity in Big River during February 2005 precipitation event (source: MFM, unpublished data).

4.4.2.6 Big River Hydrology and Streamflow

Makah Fisheries Management installed a continuous stream gage on Umbrella Creek at the Hoko-Ozette Road County Bridge on 11/03/2003 (Figure 4.12). This gage automatically measures and records river stage every 15 minutes. Discharge (ft^3/s-cfs) measurements are periodically taken at this location using current meters and wading rods at low to moderate flows, and current meters and bridgeboard cable equipment at high flows. These discharge data, along with continuous stage data, have been used to create a stage-discharge rating curve or a correlation between stage and discharge. The extreme upper end of the rating curve is defined using standard slope-area measurement techniques (Linsley et al. 1982; Sturm 2001), but still needs further refinement using current meter measurements (i.e., results are provisional).

Instantaneous discharge at Big River for water years 2004 and 2005 is plotted in Figure 4.54. In addition to these data, exceedence probabilities (% of time average flow exceeds a given discharge) are displayed that define the 90%, 49%, and 11% exceedence values. These values were calculated by the U.S. Bureau of Reclamation (USBOR) as part of water resource investigations for the Water Resource Inventory Area (WRIA) 20 Watershed Planning Process (Lieb and Perry 2004). Regression equations were developed using monthly total streamflow at Big River and monthly total streamflow at the nearby Hoko River gage (USGS 12043300). These synthesized data only represent monthly averaged flows (cubic feet per second) and exceedence of those average flows, but are very useful for defining both the general flow regime (hydrograph magnitude, duration, timing) and variability over time (1962 to 1999). Note that at any given point in time, the instantaneous discharge is much higher or lower than the average monthly flow.

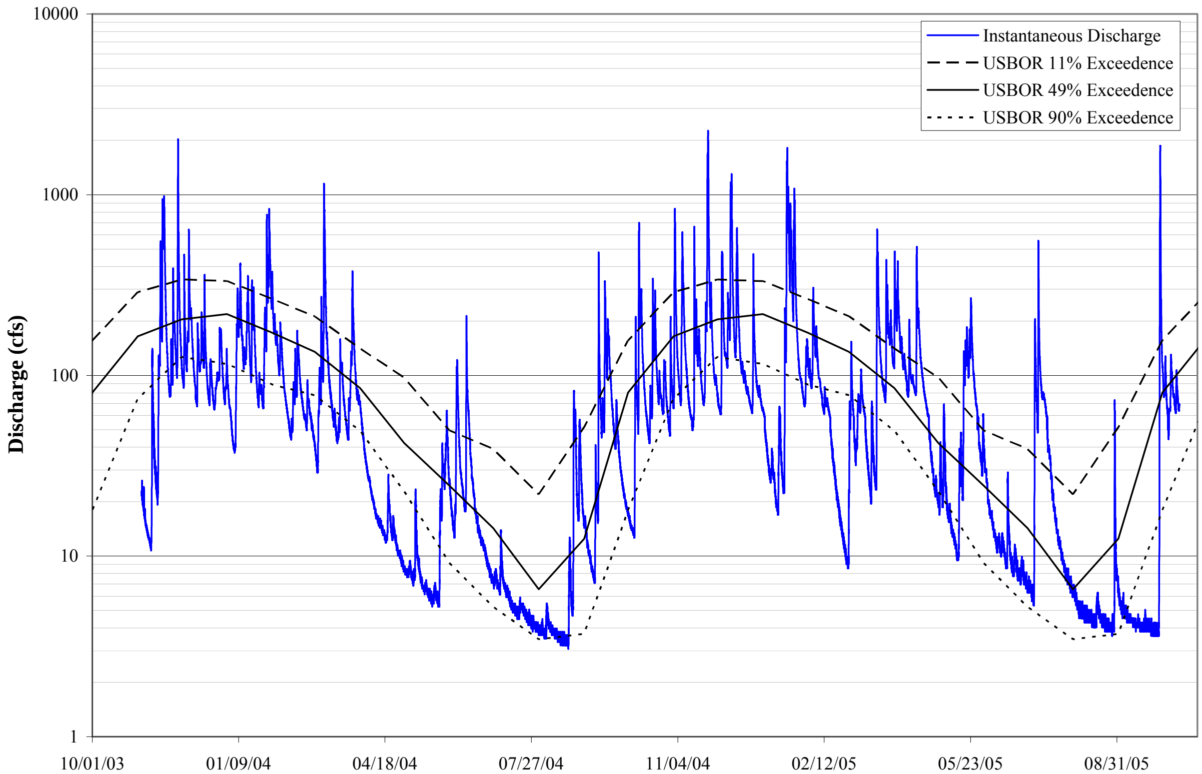

Figure 4.67. Provisional Big River discharge data plotted with USBOR synthesized monthly average streamflow exceedence curves (source: MFM unpublished data; Lieb and Perry 2004).

4.4.3 Crooked Creek

Crooked Creek is the second largest tributary to Lake Ozette (Table 1.1). Crooked Creek enters the lake along the northeast shoreline between Swan Bay and Boot Bay (Figure 3.16). Crooked Creek drains approximately 12.2 mi^2 (31.6 km^2) and includes two main tributaries. The two largest tributaries are the North and South Fork Crooked Creek, with drainage basin areas of 3.3 mi^2 (8.4 km^2) and 4.5 mi^2 (11.6 km^2) respectively. Crooked Creek flows from east to west, draining mostly low relief terrain underlain by Pleistocene age glacial drift and till deposits. From the confluence with the South Fork, the mainstem loses only about 20 meters in elevation over of a distance of more than 6 kilometers, resulting in a highly sinuous channel (i.e. Crooked Creek). Just upstream from the South Fork is the confluence between the mainstem and the North Fork. The mainstem upstream of the North Fork becomes quite small, with a basin area < 0.8 mi^2 (2.07 km^2).

4.4.3.1 Crooked Creek Floodplain Conditions

No formal assessment of Crooked Creek floodplain conditions has been conducted. A review of maps and aerial photos indicates that Crooked Creek lacks an extensive stream adjacent road network. There is no agricultural development within the watershed, as almost the entire watershed is managed for commercial timber production. Floodplain impacts are presumed to be moderate or low. Localized channel incision averaging 3.3 feet (1m) was documented by Herrera (2006) in the lower 2.5 mi (4 km) of Crooked Creek. Relic wood was functioning in portions of this section of Crooked Creek to maintain fair floodplain connectivity.

4.4.3.2 Crooked Creek Riparian Conditions

Riparian conditions in Crooked Creek vary greatly depending on location. Meyer and Brenkman (2001) report that 69% of the forest within the Crooked Creek watershed is 40 years old or less and 53% of the forest is less than 11 years old. Timber harvest operations started much later in Crooked Creek than in Umbrella Creek and Big River and substantially more old growth forest and riparian areas are unharvested. Nearly 17% of the watershed's forests were classified as > 80 years old (Meyer and Brenkman 2001). Unfortunately, the forest adjacent to almost the entire length of mainstem has been clear-cut. Smith (2000) rated the riparian conditions along the mainstem Crooked Creek as "fair" to "poor." A very small buffer was left along the south side of the middle mainstem when the area was clear-cut and this area was classified as "fair" by Smith (2000). The majority of mainstem riparian areas are now dominated by red alder. Riparian conditions are much better in the lower reaches of the South and North Forks. The South Fork flows through a stand of old growth forest before entering the mainstem. Most of the forest along the North Fork has been clear-cut, but stream side buffers were left along the lower half of the stream. The mainstem upstream of the North Fork flows mostly through a remnant forest below the anadromous barrier.

4.4.3.3 Crooked Creek Pool and LWD Conditions

Pool and LWD habitat data were collected by the Makah Tribe during the summer of 1999 and 2000 and are summarized in detail by Haggerty and Ritchie (2004). Field data were collected for almost 6,900 meters of channel within the mainstem Crooked Creek and 3,200 and 740 meters in the North and South forks respectively. Channel attribute data for Lake Ozette tributaries can be found in Appendix D. LWD and habitat data were collected within five habitat segments encompassing almost 3,000 meters of channel. Approximately 1,453 pieces of LWD were inventoried and 83%, 11%, and 5% were

characterized as conifer, deciduous, or unknown, respectively. Of the three largest tributaries to Lake Ozette, Crooked Creek had the lowest proportion of LWD categorized as deciduous. Key-piece-size LWD made up almost 4% of the LWD inventoried, but small and medium size LWD still made up 80% of all LWD inventoried.
Haggerty and Ritchie (2004) developed a habitat and LWD rating system to evaluate habitat and LWD conditions within the watershed. The results are included in Appendix E. Figure 4.68 depicts the frequency of LWD > 50 cm diameter and total LWD piece frequency per 100 meters for each habitat segment in the Crooked Creek watershed

Pool habitat conditions were also evaluated for the same habitat segments mentioned above. Haggerty and Ritchie (2004) rated several pool habitat condition variables, including pool frequency, percent pools (by length), average maximum and residual pool depth, average pool length, pools >1m deep/km, pool cover, and percent of pools formed by LWD. Figure 4.69 depicts pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in the Umbrella Creek watershed. A total of 107 pools were inventoried in the mainstem of Crooked Creek. Within the 3,000 meters of channel surveyed, the bankfull width of the mainstem changed dramatically. Below the South Fork the mainstem has an average width of about 15 meters.

Upstream of the South Fork the mainstem width is reduced to about 10 meters and upstream of the North Fork BFW averages only 5 to 6 meters. Variable stream width makes it difficult to draw straightforward connections between LWD influences and pool attributes. Nonetheless, the highest quality pools were most often associated with the largest LWD. Pools formed by key pieces were 68% deeper and twice as long as pools formed by medium or small LWD and free-formed pools without LWD. Key piece LWD represented only 4% of the LWD but formed 30% of the total pool habitat by length. Slightly more than 82% of the pools formed by LWD were formed by LWD > 50cm diameter, even though these made up only 20% of the total LWD documented (Haggerty and Ritchie 2004). Smith (2000) rated LWD conditions as “poor” in parts of the South Fork but good in the mainstem, North Fork, and parts of the South Fork.

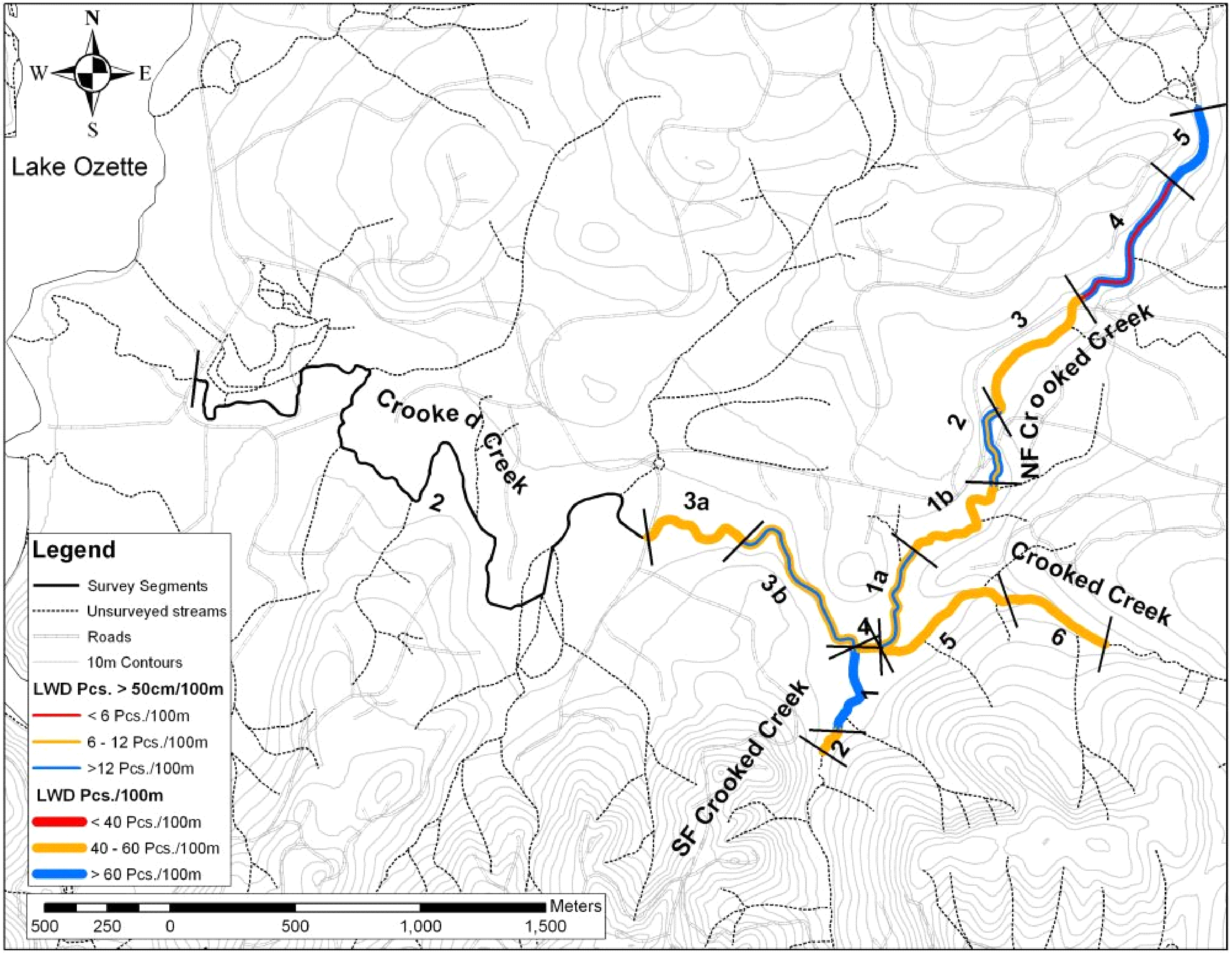

Figure 4.68. Crooked Creek watershed LWD >50cm diameter and total LWD piece count per 100 meters calculated for each habitat segment inventoried (source: Haggerty and Ritchie 2004).

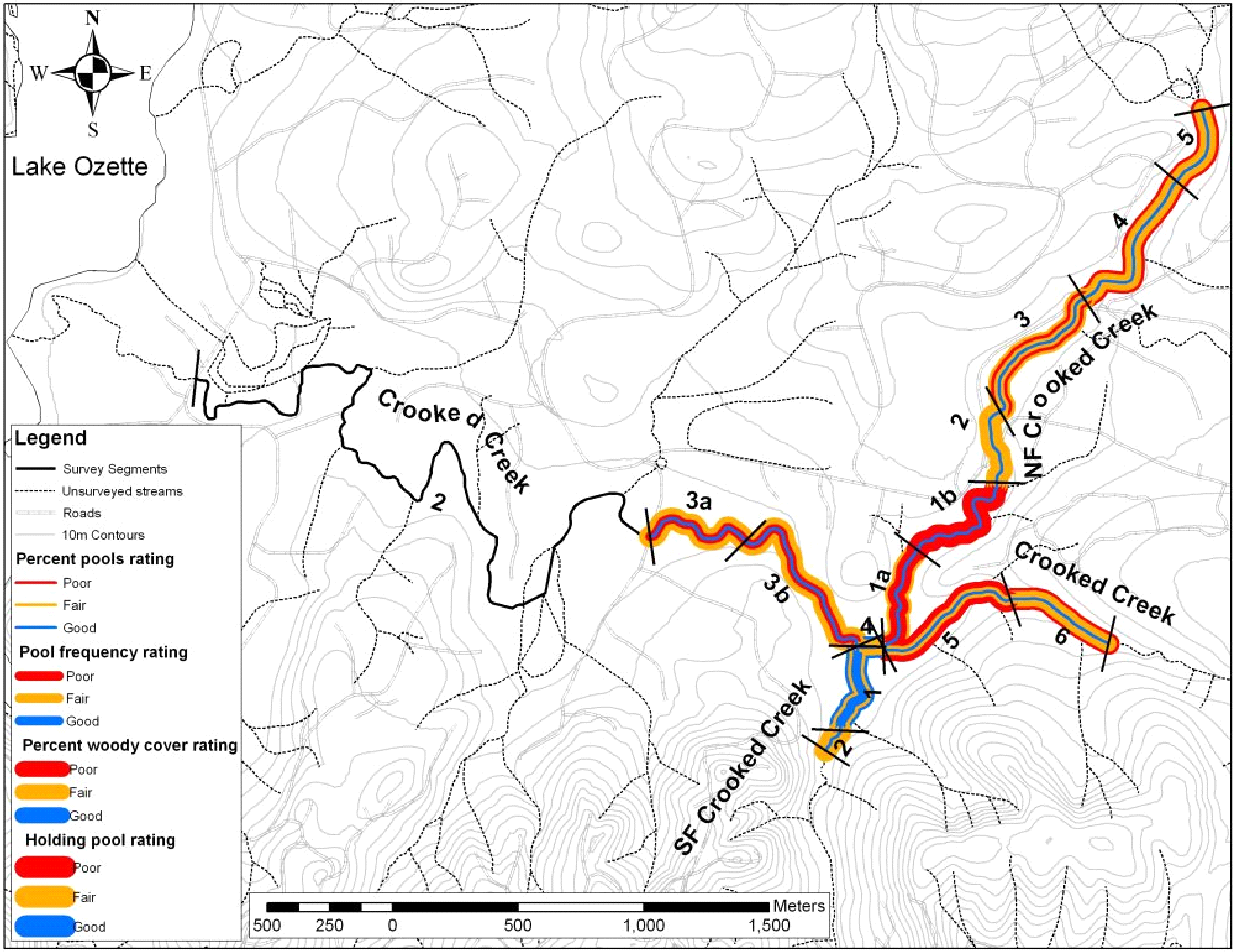

Figure 4.69. Pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in the Crooked Creek watershed (source: Haggerty and Ritchie 2004).

4.4.3.4 Crooked Creek Streambed and Substrate Conditions

Limited data are available regarding Crooked Creek substrate conditions. McHenry et al. (1994) sampled substrate conditions at one site in the mainstem (segment 3b; Figure 4.69), as well as at one site in both the South (segment 1; Figure 4.69) and North (segment 1b; Figure 4.69) forks. McHenry et al. (1994) reported the percent fine sediment (>0.85mm) in spawning gravels for the mainstem site of 14.0% (wet-sieve equivalent; dry-sieve method equal to 7.3%). McHenry et al. (1994) reported fine sediment levels in the North and South forks were 23.9% (wet-sieve equivalent; dry-sieve method equal to 13.0%) and 16.7% (wet-sieve equivalent; dry-sieve method equal to 9.3%), respectively. Martin Environmental (1999) rated spawning conditions good in the mainstem segment surveyed (1.1 mi/1.8 km of channel) in 1998, based upon the quantity of spawnable habitat in riffles and pool tail-outs. Smith (2000) rated fine sediment levels in spawning gravels "poor" in the North and South forks and fair in the mainstem. The current (2006) estimated road density for the Crooked Creek watershed is 5.7 mi/mi^2 (3.5 km/km^2; Ritchie, unpublished data). The high road densities in the Crooked Creek watershed likely contribute to the moderate to high levels of fine sediment observed in spawning gravels. Additional substrate characterization for Crooked Creek can be found in Haggerty and Ritchie (2004).

4.4.3.5 Crooked Creek Water Quality

Water quality data for Crooked Creek are even more limited than for Umbrella Creek and Big River. Bortleson and Dion (1979) collected a very limited quantity of water quality data in Crooked Creek, which included temperature point samples, discharge, and specific conductivity. The most comprehensive water quality dataset is summarized by Meyer and Brenkman (2001). Meyer and Brenkman (2001) collected water temperature, dissolved oxygen, pH, specific conductivity, and turbidity data monthly from July 20, 1993 through November 30, 1994. Table 4.15 contains a summary of water quality sampling data for Crooked Creek from Meyer and Brenkman (2001).

Table 4.15. Summary of water quality data collected in Crooked Creek from July 20, 1993 through November 30, 1994 (source: Meyer and Brenkman 2001).

	Stream Temperature (°C)	**pH**	**Specific Conductivity (uS/cm)**	**Dissolved Oxygen (mg/l)**	**Turbidity (NTU)**
Minimum	2.6	5.7	17.9	7.5	0.0
Maximum	16.1	7.2	53.2	12.0	41.0
Mean	10.2	6.5	38.2	10.0	8.4
Number Months Sampled	n=20	n=15	n=20	n=16	n=15

Additional stream temperature monitoring was also conducted using a thermograph and data logger during the summer of 1993 and 1994 (MFM unpublished data; Meyer and

Brenkman 2001). A review of available temperature data for lower Crooked Creek indicates that data were collected during four summers from 1990 through 1997. Temperature data were collected on a total of 335 days between June 1 and September 30 (1990-1997). Maximum annual temperatures were recorded between July 9 (1990) and August 5 (1997; Table 4.16). The 7-day moving average maximum daily temperatures observed from 1990 through 1997 are depicted in Figure 4.70. Figure 4.71 depicts the number of days sampled and the number of days when water temperature exceeded 16, 18, and 20°C.

Table 4.16. Summary of maximum daily stream temperature observations from lower Crooked Creek during temperature monitoring from 1990 through 1997 (source: MFM, unpublished data; Klinge 1991; Meyer and Brenkman 2001).

Year	Number of Days Sampled (6/1 to 9/30)	Date of Peak Temperature	Peak Temp (C)	Date of Peak 7-Day Moving Average Daily Maximum Temp.	Peak 7-Day Mov. Avg. Daily Max. Temp. (C)
1990	122	7/9	18.3	8/8	17.8
1993	72	8/4	20.7	8/7	19.2
1994	107	7/20	20.3	8/15	19.3
1997	34	8/5	18.1	8/10	17.5

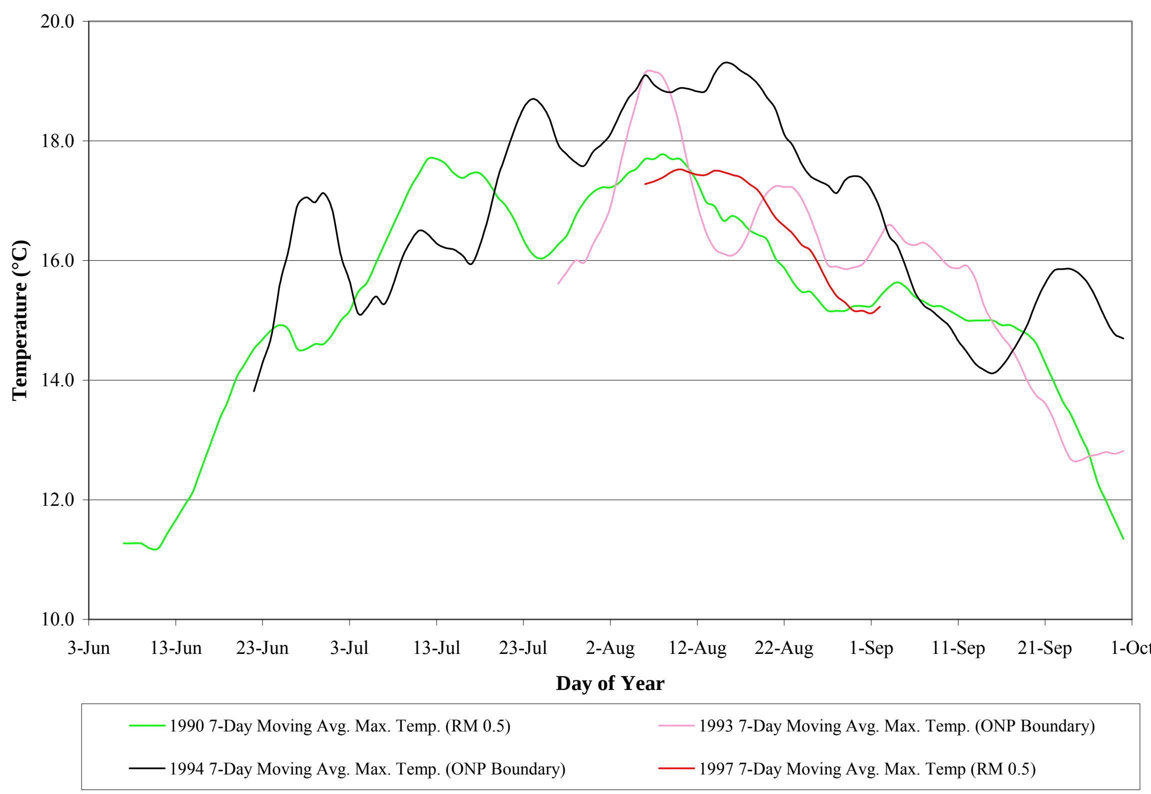

Figure 4.70. Lower Crooked Creek 7-day moving average daily maximum stream temperature 1990-1997 (source: MFM, unpublished stream temperature data; Klinge 1991; Meyer and Brenkman 2001).

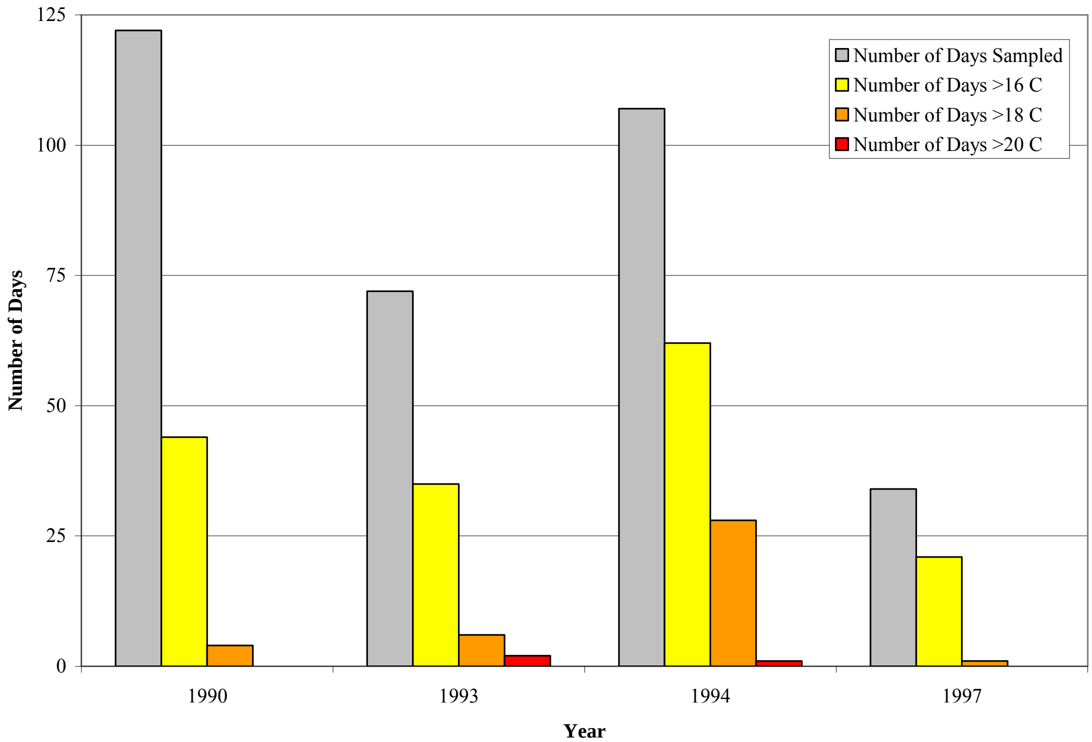

Figure 4.71. Number of days sampled and the number of days stream temperature exceeded 16, 18, and 20 °C in Lower Crooked Creek from 1990 through 1997 (source: MFM, unpublished stream temperature data; Klinge 1991; Meyer and Brenkman 2001).

Maximum daily stream temperature exceeded 16°C on 162 days (48% of the days sampled) between June 1 and September 30 (1993-1997). During the warmest period of summer, July 15 through August 15 data were collected on 106 days. Stream temperatures exceeded 16°C on 89 days (84% of the days sampled). Stream temperature exceeded 18°C on 46 days (28% of the days sampled). Stream temperatures exceeding 20°C were recorded on 3 days (<1% of the days sampled). Over 78% of the days where maximum stream temperature was greater 18°C were between July 15 and August 15 (this period represented 32% of the time period for which data were collected). Only 9 (<22%) stream temperatures greater 18°C were recorded outside of the July 15 to August 15 period (68% of the data were collected outside of this time period).

Crooked Creek pH levels were documented by Meyer and Brenkman (2001) to exhibit the greatest variation in the tributaries sampled, ranging from 5.7 to 7.2. Turbidity levels were nearly an order of magnitude less during the November 30, 1994 storm event than those observed in Big River and Umbrella Creek. Meyer and Brenkman (2001) concluded that water quality conditions were marginal in Crooked Creek. Specific water quality concerns raised by Meyer and Brenkman (2001) were related to dissolved oxygen levels below 8.0 mg/l and pH levels below 6.0. Smith (2000) rated the water quality "poor" for Crooked Creek based upon stream temperatures consistently exceeding the

Washington State Water Quality Standards. Jacobs et al. (1996) voiced no concern over the dissolved oxygen or pH levels in Crooked Creek.

Makah Fisheries Management installed a continuous submersible turbidity sensor on Crooked Creek on 9/25/2005, with the goal of detecting long-term (5-10 plus year) trends in turbidity and suspended sediment concentration. The sensor is deployed from a bank-mounted boom that reaches out over the channel and places the sensor toward the center of the channel in well-mixed water (methods used are similar to those in Big River and Umbrella Creek. For additional details see Sections 4.4.1.5 and 4.4.2.5).

Median turbidity values (15-minute) are plotted in Figure 4.72, along with discharge. Turbidity (and SSC) peaks in Crooked Creek usually last for less than a day, depending on the length of the flood pulse event. Turbidity rises sharply on the rising limb of the discharge hydrograph and falls more rapidly than discharge on the recession limb. These lower turbidity (and SSC) values on the recession limb at the same discharge (i.e., hysteresis) are a result of the initial flush of readily available sediment from both upland and channel sources (Hicks and Gomez 2003). Thus in Crooked Creek, turbidity and suspended sediment concentrations are dependent on the supply of fine sediment from both upland and channel sources.

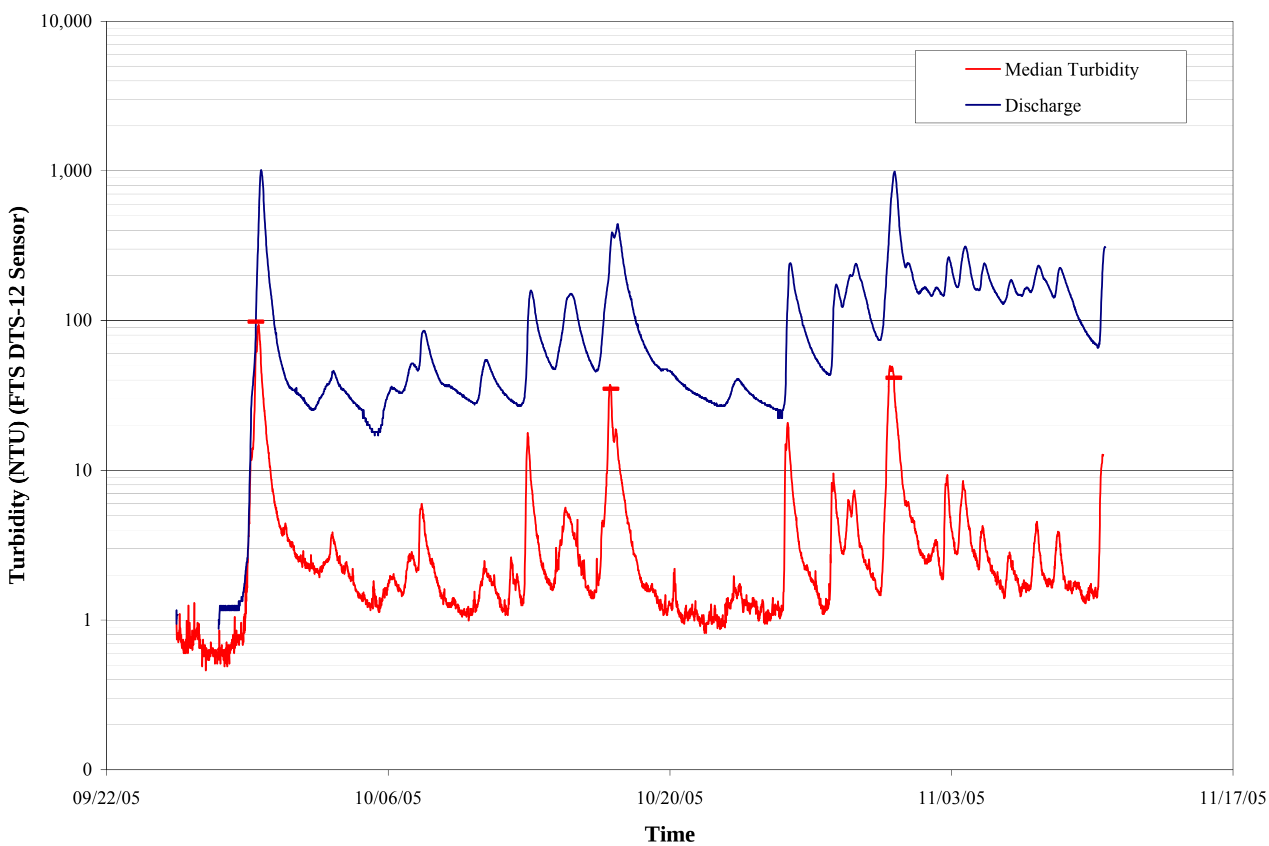

Figure 4.72. Preliminary results from continuous turbidity readings and provisional stream discharge data for Crooked River (source: MFM, unpublished data).

4.4.3.6 Crooked Creek Hydrology and Streamflow

Makah Fisheries Management installed a continuous stream gage on Crooked Creek at the 5830 Road Bridge on 12/19/2003 (Figure 4.12). This gage automatically measures and records river stage every 15 minutes. Discharge (ft^3/s) measurements are periodically taken at this location using current meters and wading rods at low to moderate flows, and current meters and bridgeboard cable equipment at high flows. These discharge data, along with continuous stage data, have been used to create a stage-discharge rating curve or a correlation between stage and discharge. The extreme upper end of the rating curve is defined using standard slope-area measurement techniques (Linsley et al. 1982; Sturm 2001), but still needs further refinement using current meter measurements (i.e., results are provisional). Instantaneous discharge at Crooked Creek for water years 2004 and 2005 are plotted in Figure 4.73.

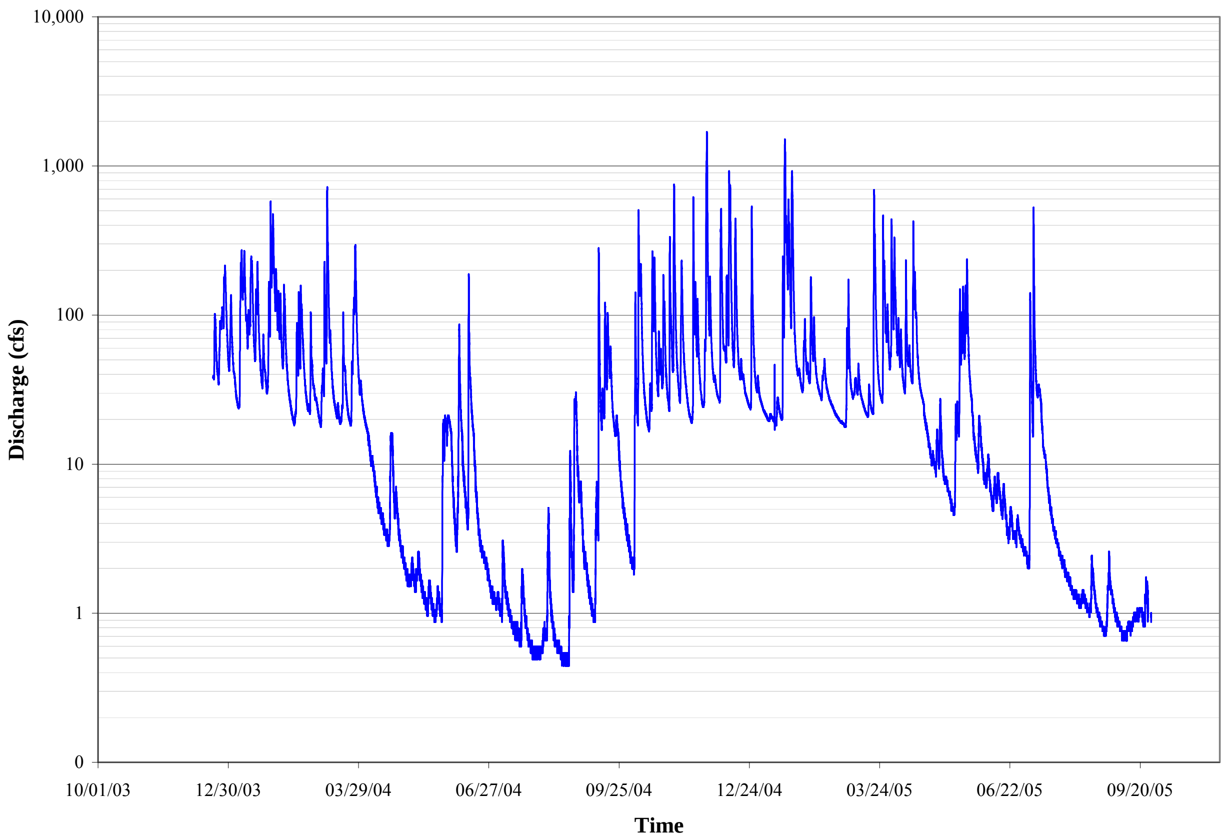

Figure 4.73. Provisional Crooked Creek discharge data (source: MFM, unpublished data).

4.4.4 Coal Creek

Coal Creek is a right-bank tributary to the Ozette River that enters just downstream from the lake's outlet (Figure 3.16). Coal Creek is the fourth largest tributary in the Ozette watershed and the largest tributary to the Ozette River. The Coal Creek watershed drains approximately 4.57 mi^2 (11.84 km^2) and consists of the mainstem of Coal Creek, two main unnamed tributaries (20.0050 and LBT 22,772), and several smaller tributaries. The mainstem is a predominantly south flowing stream. The western and southern portions of the watershed are underlain with Pleistocene age glacial till and drift deposits with very low relief (maximum elevations of about 200-300 feet above sea level). The headwaters of Coal Creek are located in the northeastern portion of the watershed and are underlain by Oligocene-Eocene aged marine sedimentary rock units. Approximately 95% of the watershed is privately owned (Herrera 2006); the remaining land is owned by WDNR. Nearly 100% of the watershed is managed for industrial forestry and has been clear-cut at least once.

4.4.4.1 Coal Creek Floodplain Conditions

No comprehensive, field-based assessment of Coal Creek floodplain conditions has been conducted, but it seems clear that floodplain connectivity is problematic in the lower reaches of Coal Creek. Smith (2000) does not provide an overall rating for floodplain conditions in Coal Creek, but cites J. Freudenthal as stating that channel incision is a problem in Coal Creek. Herrera (2006) reported that the lower 1.25 miles (2.0 km) of Coal Creek has undergone approximately 3.3 feet (1m) of channel incision over the last 50 years. Herrera (2006) found significant evidence of floodplain disconnection in lower Coal Creek, as well as the presence of an inset floodplain, which they suggested was an indicator that the channel may be re-stabilizing. Herrera (2006) also found a number of distributary channels near the confluence with the Ozette River and suggested that historically, when a more dynamic deltaic floodplain existed, prior to channel incision, these channels would have transported high flows toward Lake Ozette. Herrera (2006) concluded that much of the channel incision in Coal Creek is likely a response to wood removal from the Ozette River.

4.4.4.2 Coal Creek Riparian Conditions

Riparian areas in Coal Creek are highly altered from their historical conditions. Nearly 100% of the old growth riparian forest has been clear-cut along the mainstem and tributaries. Forest age structure is similar to that seen in other Ozette sub-basins where nearly all the timber stands are less than 50 years old. Orthophotos taken in the summer of 2000 reveal that most of the riparian areas are dominated by young stands of red alder. Very few if any residual large conifer trees are present in the watershed. Lower Coal Creek flows through a patch of large second growth forest and contains a mix of both conifer and hardwoods. The upper mainstem consists of riparian forests dominated by conifer. Prior to timber harvest, riparian forests were primarily composed of Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*). Residual in-channel LWD in some areas provides evidence of the massive trees that once grew along Coal Creek. Riparian conditions in the two primary tributaries to Coal Creek are also highly degraded from the pre-disturbance condition. Mixed stands of young to medium age forests dominate the riparian composition of the main tributaries to Coal Creek and some of its larger tributaries.

4.4.4.3 Coal Creek Pool and LWD Conditions

Pool and LWD habitat data were collected by the Makah Tribe during the summer of 1999 and 2000 in Coal Creek and are summarized in detail by Haggerty and Ritchie (2004). Habitat data were collected in over 4.8 miles (7.8 km) of channel within the mainstem of Coal Creek and 1.5 miles (2.4 km) in the two largest tributaries. Channel attribute data for Lake Ozette tributaries can be found in Appendix D. LWD and habitat data were collected in 14 habitat segments encompassing the 4.8 miles of channel in the mainstem. A total of 5,488 pieces of LWD were inventoried, of which 73%, 26%, and 1% were categorized as conifer, deciduous, and unknown respectively. Only 1% of the pieces inventoried were classified as key pieces. Approximately 89% of the pieces inventoried were <50cm in diameter. Haggerty and Ritchie (2004) developed a habitat and LWD rating system to evaluate habitat and LWD conditions within the watershed. The results are included in Appendix E. Figure 4.74 depicts the frequency of LWD > 50 cm diameter and total LWD piece frequency per 100 meters for each habitat segment in Coal Creek watershed. Pool habitat conditions were also evaluated for the same habitat segments mentioned above. Haggerty and Ritchie (2004) rated several pool habitat condition variables, including pool frequency, percent pools (by length), average maximum and residual pool depth, average pool length, pools >1m deep/km, pool cover, and percent of pools formed by LWD. Figure 4.75 depicts pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in the Coal Creek watershed. A total of 348 pools were documented in the mainstem of Coal Creek. The highest quality pools were most often associated with the largest LWD pieces. Key-piece-size LWD made up only 1% of the total LWD abundance and had a frequency of only 0.07 pieces/CW, but formed 15% of the total pool habitat (by length). Large (Key, L+, and L/L-) LWD made up 11% of the total LWD abundance, had a frequency of about 0.63 pieces/CW, and formed 51% of the total pool habitat.

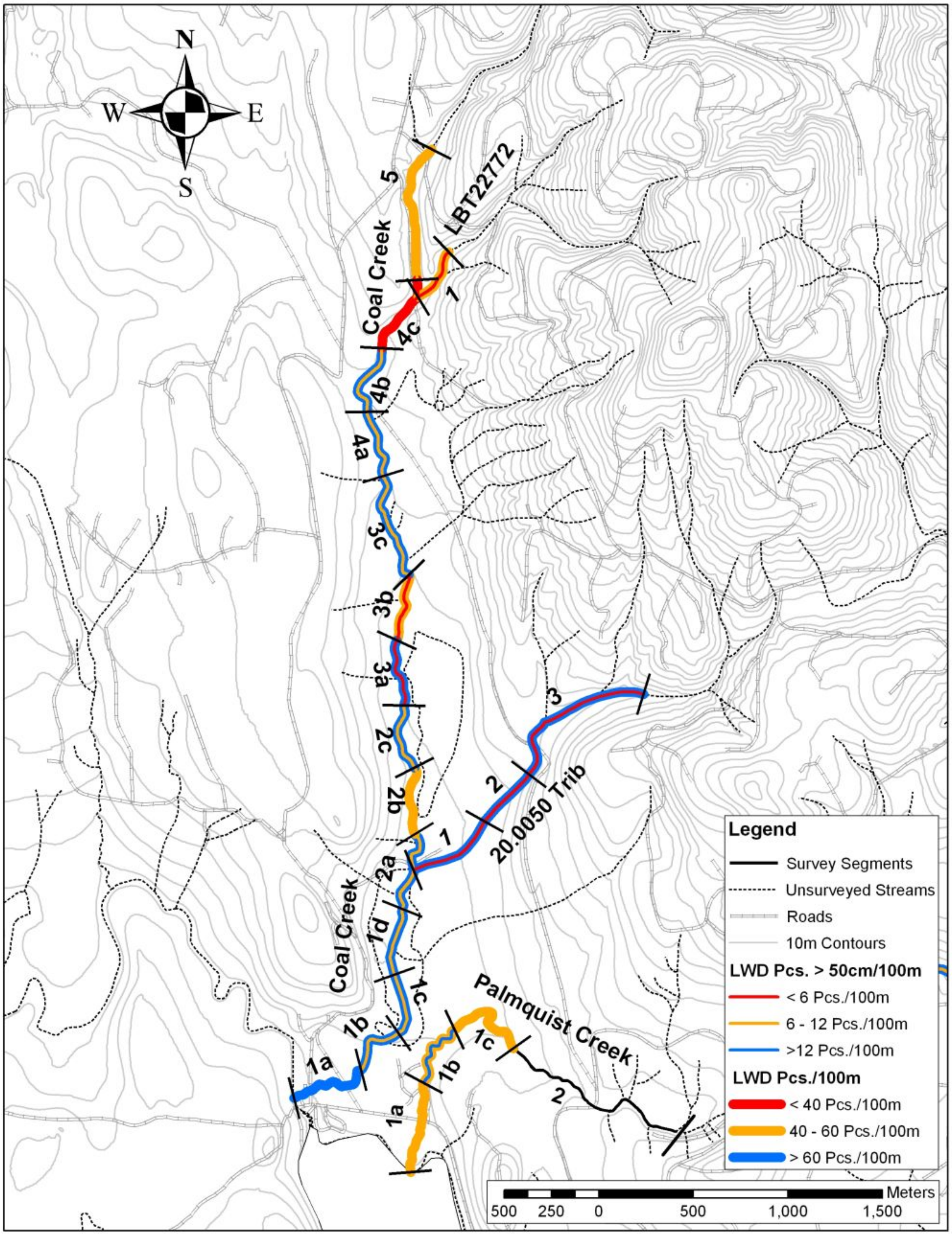

Figure 4.74. Coal Creek watershed LWD >50cm diameter and total LWD piece count per 100 meters calculated for each habitat segment inventoried (source: Haggerty and Ritchie 2004).

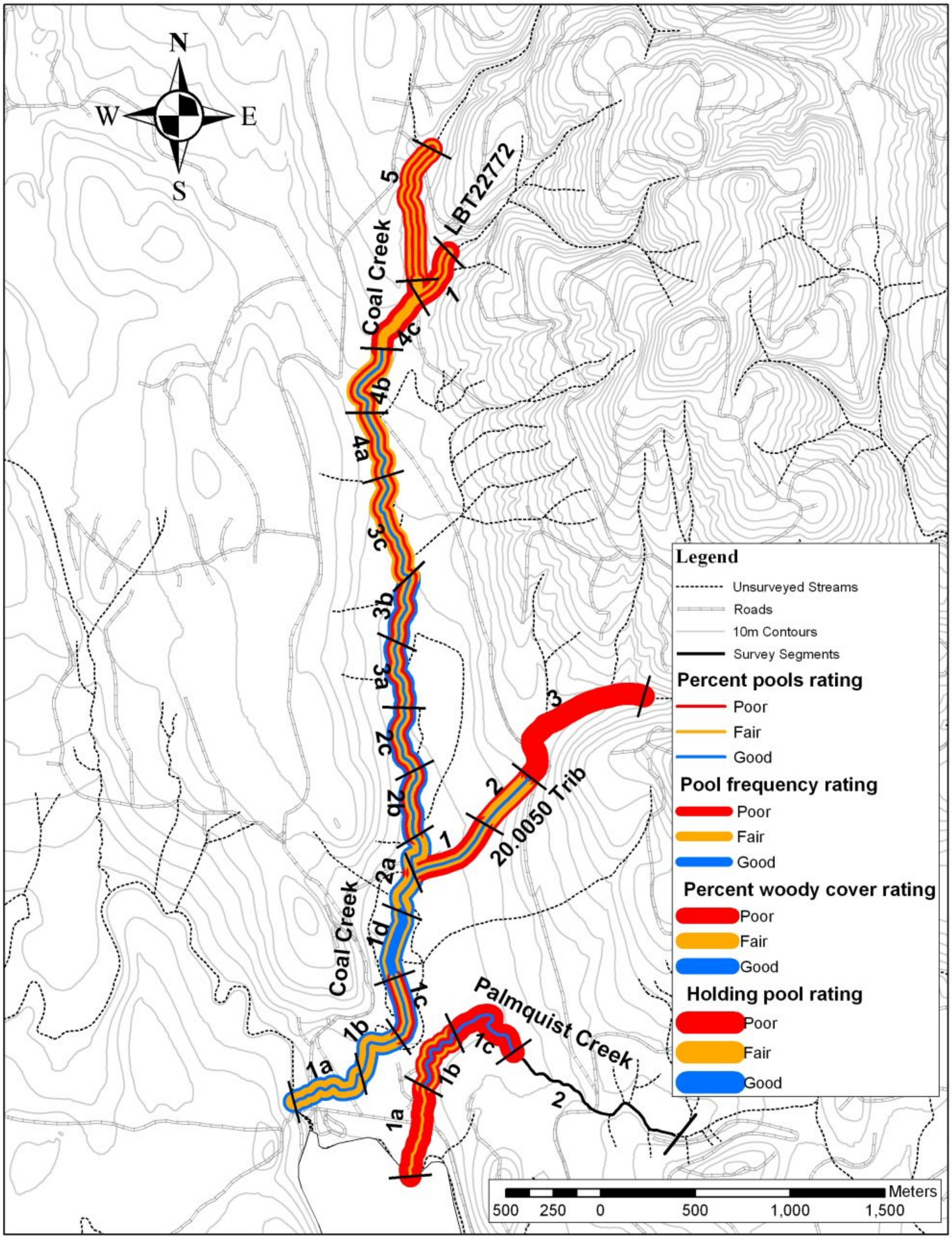

Figure 4.75. Coal Creek pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in the Coal Creek watershed (source: Haggerty and Ritchie 2004).

Riparian forest removal has dramatically decreased the quantity and quality of trees available for recruitment into Coal Creek. Habitat and LWD data collected in Coal Creek illustrate the importance of large and key-piece-sized LWD in forming high quality habitat features. Recent recruitment of small and medium size LWD appears incapable of producing the same habitat quality and complexity as seen in those habitats formed by LWD > 50 cm diameter. As described above, the LWD conditions in most habitat segments ranked poor for key piece frequency and nearly 79% ranked fair or poor for large piece frequency. The loss of large and key-piece-sized LWD has reduced pool quality throughout most of Coal Creek by reducing the number of high quality habitats. Figure 4.76 illustrates the role of the largest LWD in forming deep pools with sufficient cover.

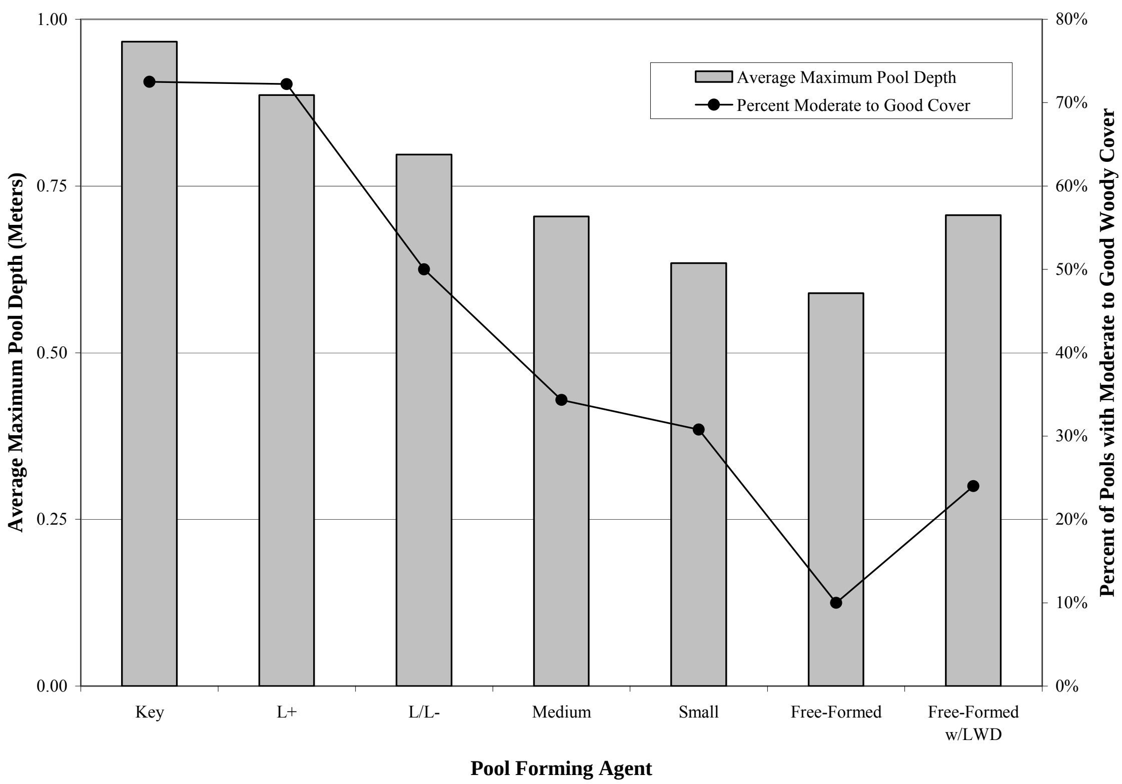

Figure 4.76. Relationship between primary pool forming agent and pool depth and percent pool cover for Coal Creek (source: Haggerty and Ritchie 2004). Note: L+ = LWD>50cm diameter and > 5m length; L/L- = LWD> 50cm diameter < 5m length; medium = LWD 50-20cm diameter; small = LWD 10-20cm diameter; moderate woody cover = 6-20% cover; and good woody cover = >20% woody cover.

4.4.4.4 Coal Creek Streambed and Substrate Conditions

Spawning gravel quality samples have not been collected in Coal Creek. General substrate classifications by habitat segment based on field observations are included in Haggerty and Ritchie (2004). Substrate conditions in segment 1 are described as chiefly composed of mud, silt, and sand in the lower 600 feet of Coal Creek. Gravel patches were noted in several locations upstream in segment 1, but in general the substrate was dominated by sand. Haggerty and Ritchie (2004) describe the substrate conditions in segment 2 as containing high levels of fine-grained materials; gravel bars and spawning gravel are present in many locations but many gravel areas were covered in silt and sand. No substrate observations were included for segment 3. Segment 4 was described as dominated by gravel but grading to cobble near the segment 4/5 break. Segment 5 is composed primarily of cobble, gravel, and boulders. While fine sediment in spawning gravel data are not available for Coal Creek, it is likely that fine sediment levels are similar to those observed in other low gradient Ozette tributaries. The current (2006) estimated road density for the Coal Creek watershed is 6.1 mi/mi^2 (3.8 km/km^2; Ritchie, unpublished data). Herrera (2006) found that sediment input and transport have increased significantly during the last 50 years; they attribute increased sediment loads in Coal Creek to road construction, clear-cutting, and channel incision.

4.4.4.5 Coal Creek Water Quality

Water quality data for Coal Creek are even more limited than for Umbrella Creek and Big River. Bortleson and Dion (1979) collected a very limited quantity of water quality data in Coal Creek, which included temperature point samples, discharge, and specific conductivity. The most comprehensive water quality dataset is summarized by Meyer and Brenkman (2001). Meyer and Brenkman (2001) collected water temperature, dissolved oxygen, pH, specific conductivity, and turbidity data monthly from December 16, 1993 through November 30, 1994 at the Seafield Mainline Bridge near Ozette River. Table 4.15 summarizes water quality sampling data for Coal Creek from Meyer and Brenkman (2001).

Table 4.17. Summary of water quality data collected in Crooked Creek from July 21, 1993 through November 30, 1994 (source: Meyer and Brenkman 2001).

	Stream Temperature (°C)	**pH**	**Specific Conductivity (uS/cm)**	**Dissolved Oxygen (mg/l)**	**Turbidity (NTU)**
Minimum	5.7	5.7	27.3	5.7	1.5
Maximum	14.8	6.8	76.2	11.4	48.3
Mean	9.8	6.4	54.9	9.5	12.5
Number Months Sampled	n=14	n=14	n=14	n=14	n=10

In recent years additional water quality data have been collected in Coal Creek near the Ozette River at the Seafield Mainline Bridge. Makah Fisheries Management began collecting water quality data in Coal Creek in January 2004. Data collection is ongoing and typically occurs monthly, but sampling frequency increases to approximately twice per month during spring and summer months. Table 4.18 summarizes the results of water quality sampling by MFM in Coal Creek. Water quality conditions measured by MFM are roughly within the same range of conditions measured by Meyer and Brenkman (2001). Some of the minor differences between datasets can be attributed to increased sample frequency during May, June, and July in the MFM dataset.

Table 4.18. Summary of water quality data collected in Coal Creek from January 15, 2004 through October 7, 2005 (source: MFM, unpublished water quality data).

	Stream Temperature (°C)	**pH**	**Specific Conductivity (uS/cm)**	**Dissolved Oxygen (mg/l)**	**Turbidity (NTU)**
Minimum	5.2	5.8	30.7	8.1	0.0
Maximum	15.0	7.0	70.4	15.1	57.0
Mean	10.1	6.5	55.5	11.0	4.0
Number Sample Points	n=31	n=31	n=29	n=31	n=31

Stream temperature monitoring has also been conducted using thermographs and data loggers. Green Crow, Quileute Natural Resources (QNR), and MFM have collected data at various sites along Coal Creek since 1997. A review of available temperature data for Coal Creek found that data were collected during seven summers from 1997 through 2005. Stream temperature data were collected at several sites throughout the mainstem of Coal Creek from 1997 through 1999. Figure 4.77 depicts maximum daily stream temperature by river mile for six sites in Coal Creek during the summer of 1997. These data show that the maximum stream temperature decreased from RM 4 to RM 3 and then increased from RM 3 to RM 1.43. It is suspected that cooler tributary waters entering between RM 1.43 and 1.25 are responsible for the observed cooling in this reach. Nevertheless, the highest stream temperatures were observed at the lowest monitoring station.

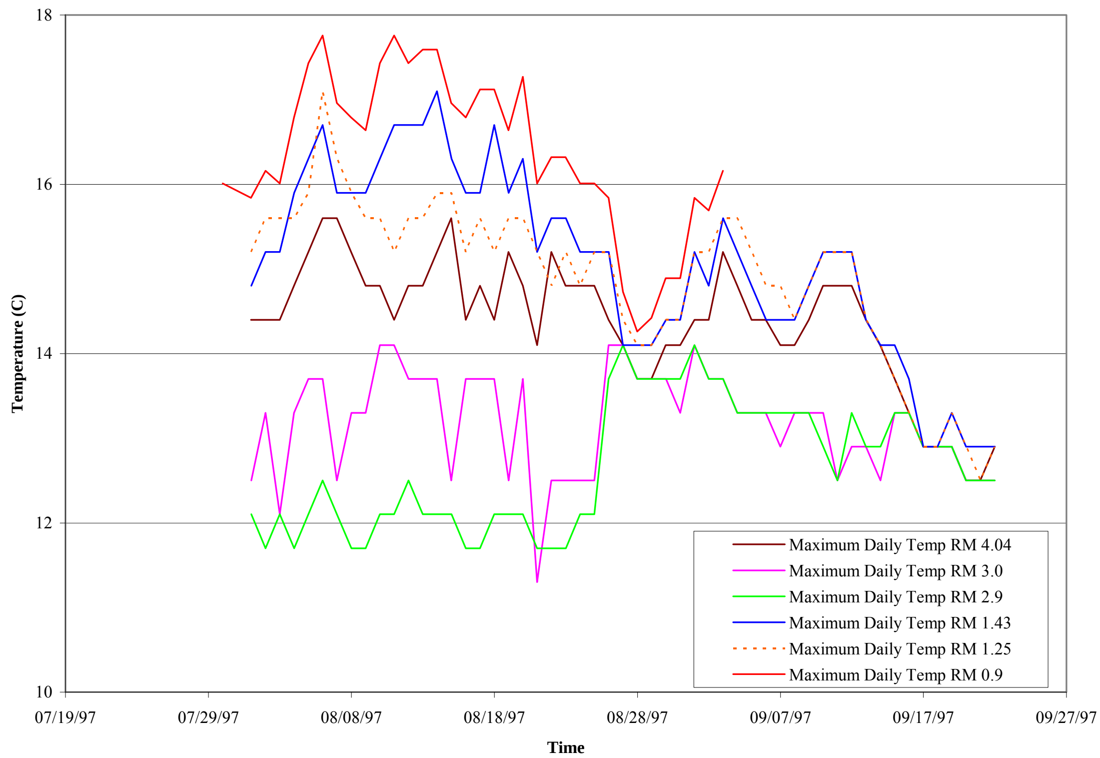

Figure 4.77. Coal Creek maximum daily stream temperature at six sites during the summer of 1997 (source: MFM and Green Crow, unpublished data).

Stream temperature data were collected at six sites during the summer of 1999 and are depicted in Figure 4.78. These data show quite a different trend than data collected in 1997. Maximum daily stream temperatures were the lowest farthest upstream, and highest at the lowest point measured downstream. Some of the differences between 1997 and 1999 can partially be explained by the lower maximum daily temperatures observed in 1999. Another explanation could be that stations monitored in 1999 did not include sites directly downstream from major tributaries.

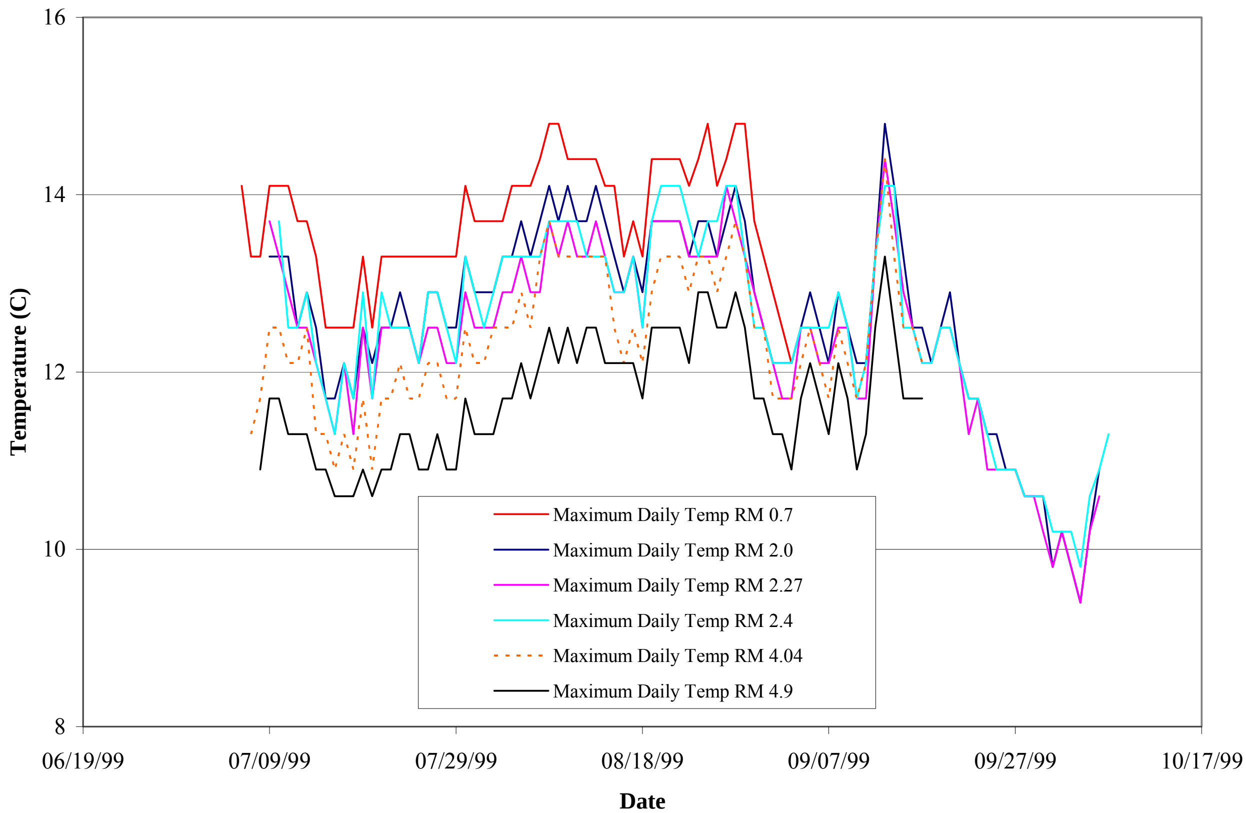

Figure 4.78. Coal Creek maximum daily stream temperature at six sites during the summer of 1999 (source: QNR and Green Crow, unpublished data).

In order to compare stream temperature data across multiple years, Coal Creek data were evaluated from RM 0.5 to RM 0.9. This reach was selected due to the fact that the most number of years of data are available and stream temperatures are highest in this reach. Temperature data were collected on a total of 640 days between June 1and September 30 (1997-2005). Maximum annual temperatures were recorded between June 6 (2003) and August 27 (1998; Table 4.19). The 7-day moving average maximum daily temperatures observed from 1997 through 2005 are depicted in Figure 4.79. Figure 4.80 depicts the number of days sampled and the number of days when water temperature exceeded 16, 18, and 20°C.

Table 4.19. Summary of maximum daily stream temperature observations from lower Umbrella Creek during temperature monitoring from 1997 through 2005 (sources: MFM QNR, and Green Crow, unpublished data).

Year	Number of Days Sampled (June 1 to September 30)	Date(s) of Peak Temperature	Peak Temperature (C)	Date of Peak 7-Day Moving Average Daily Maximum Temp.	Peak 7-Day Moving Average Daily Maximum Temperature (C)
1997	35	8/5	17.8	8/15	17.4
1998	90	8/27	17.1	8/31	15.5
1999	60	8/8	14.8	8/13	14.5
2002	104	7/23	16.7	7/25	16.1
2003	120	6/6	16.7	7/24	15.7
2004	114	7/24	18.1	7/24	17.4
2005	117	8/1	15.9	8/2	15.4

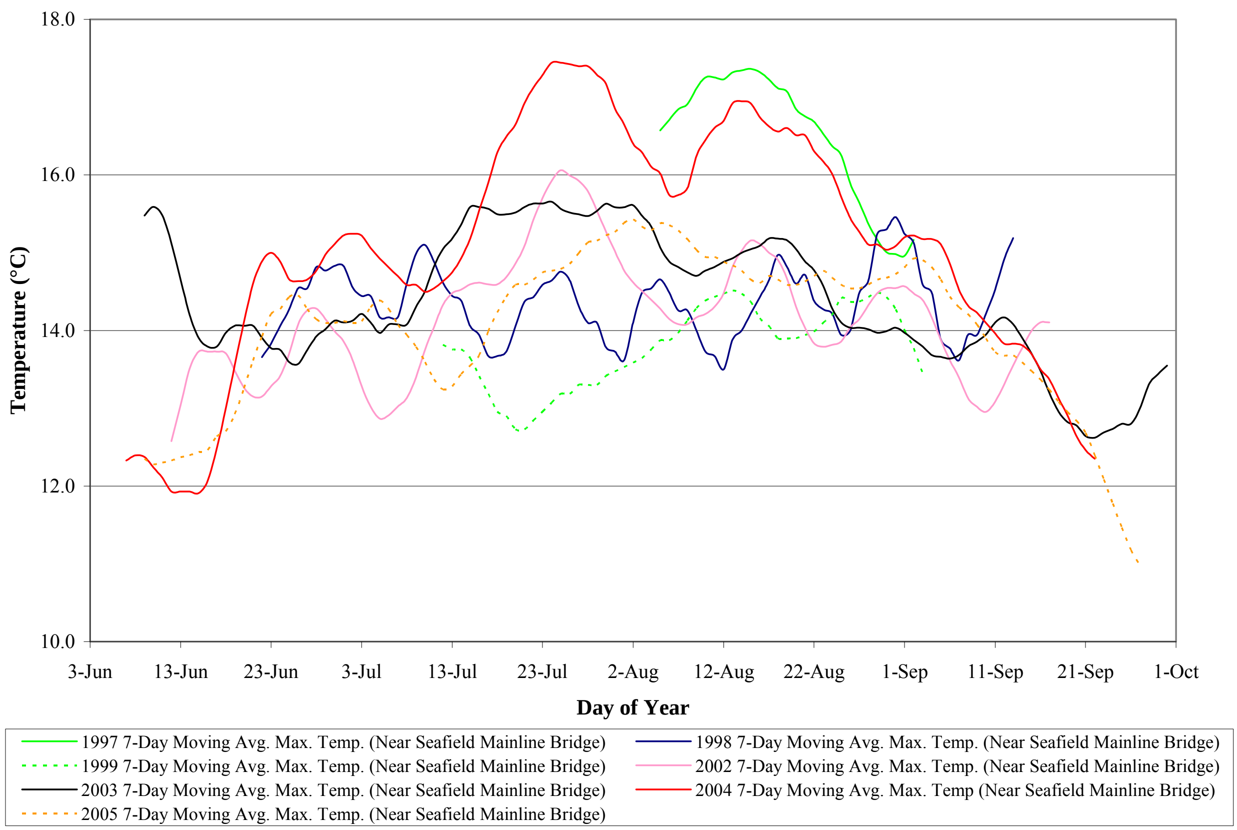

Figure 4.79. Coal Creek 7-day moving average maximum stream temperature near Seafield Mainline Bridge (MFM, Green Crow, and QNR, unpublished stream temperature data).

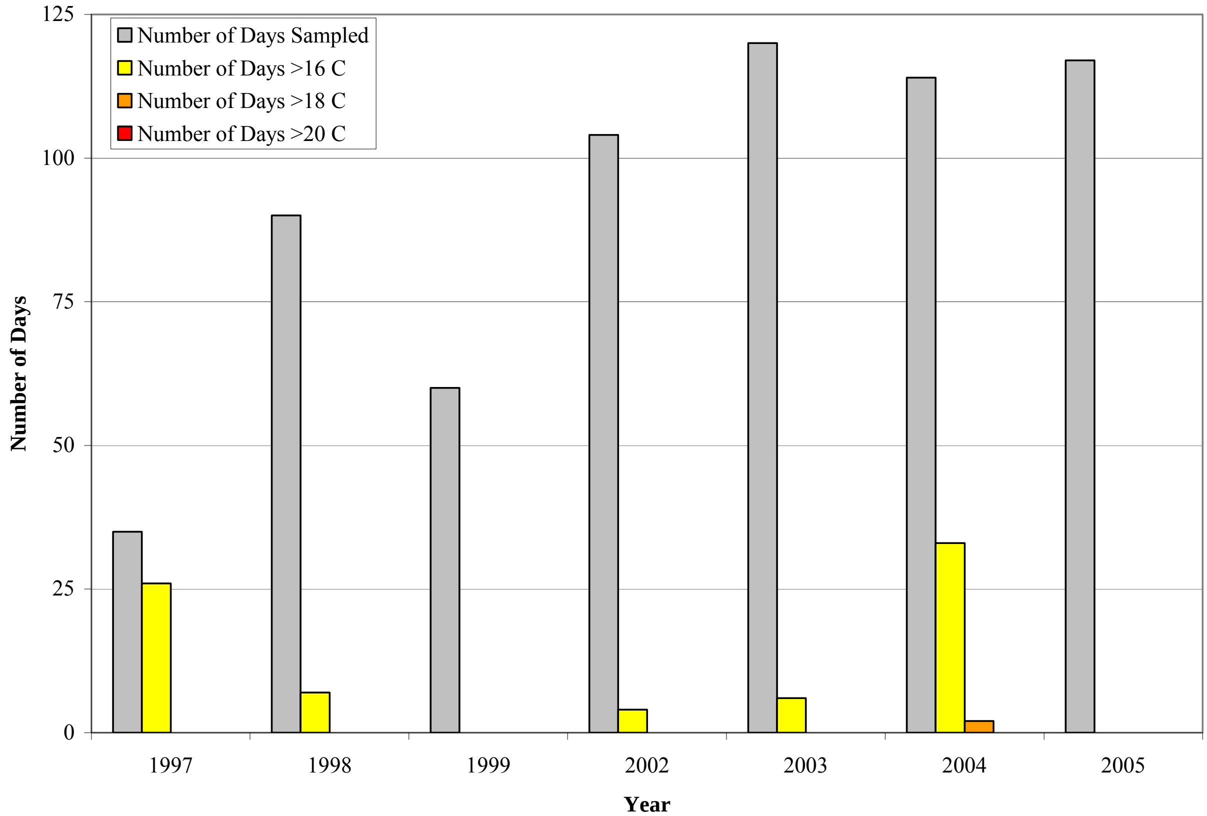

Figure 4.80. Number of days sampled and the number of days stream temperature exceeded 16, 18, and 20°C in Lower Coal Creek from 1997 through 2005 (MFM, Green Crow, and QNR, unpublished stream temperature data).

Maximum daily stream temperatures exceeded 16°C on 76 days (12% of the days sampled) between June 1 and September 30 (1997-2005). During the warmest period of summer, July 15 through August 15, data were collected on 209 days. Stream temperatures exceeded 16°C on 48 days (23% of the days sampled). Stream temperatures exceeded 18°C on 2 days (1% of the days sampled). Stream temperatures in Coal Creek are much cooler than those observed in the Ozette River, Big River, Umbrella Creek, and Crooked Creek. Most of the riparian areas that were clear-cut in the 1950s and 1960s have grown back in dense stands of second growth and appear capable of maintaining enough shade to prevent excessive temperatures.

4.4.4.5.1 Turbidity and Suspended Sediment Concentration

Makah Fisheries Management installed a continuous submersible turbidity sensor on Coal Creek on National Park Service land on 10/15/2005, with the goal of detecting long-term (5-10 plus year) trends in turbidity and suspended sediment concentration. The sensor is deployed from a bank-mounted boom that reaches out over the channel and places the sensor toward the center of the channel in well-mixed water (methods used are similar those in Big River and Umbrella Creek. For additional details see Sections 4.4.1.5 and 4.4.2.5). In addition, at Coal Creek an automated pump sampler is controlled by the same data logger as the turbidity sensor. Pump samples of SSC are collected at different turbidity thresholds or levels. These samples are collected throughout the range of turbidity and are used to correlate turbidity to suspended sediment concentration. Pump samples are processed in whole through filtration at a laboratory and used to calculate SSC.

Median turbidity values (15-minute) are plotted in Figure 4.81, along with discharge and points in time when turbidity threshold pump samples were taken. The relationships between median turbidity and suspended sediment concentration are shown in Figure 4.82. Calculated suspended sediment concentration and discharge data are depicted in Figure 4.83 for the period October 2005 to January 2006.

As shown in these figures, turbidity and SSC peaks in Coal Creek usually last for less than a day, depending on the length of the flood pulse event. The relationship between median turbidity and suspended sediment concentration is excellent (Figure 4.82), resulting in reliable estimates of SSC (Figure 4.83). This type of relationship is being developed for other Ozette tributaries. For the short period of record at Coal Creek, data indicate that turbidity and SSC values are generally correlated to discharge on both the rising and falling limbs of the hydrograph, with little hysteresis. For example, the relationship between median turbidity, SSC, and discharge at Coal Creek are shown in Figure 4.84 for a single storm event on 11/10/05, displaying this single relationship. A single relationship (or curve) between turbidity (or SSC) and discharge indicates an unlimited suspended sediment supply with transport dependent on available flow energy (Hicks and Gomez 2003; Nistor and Church 2005)

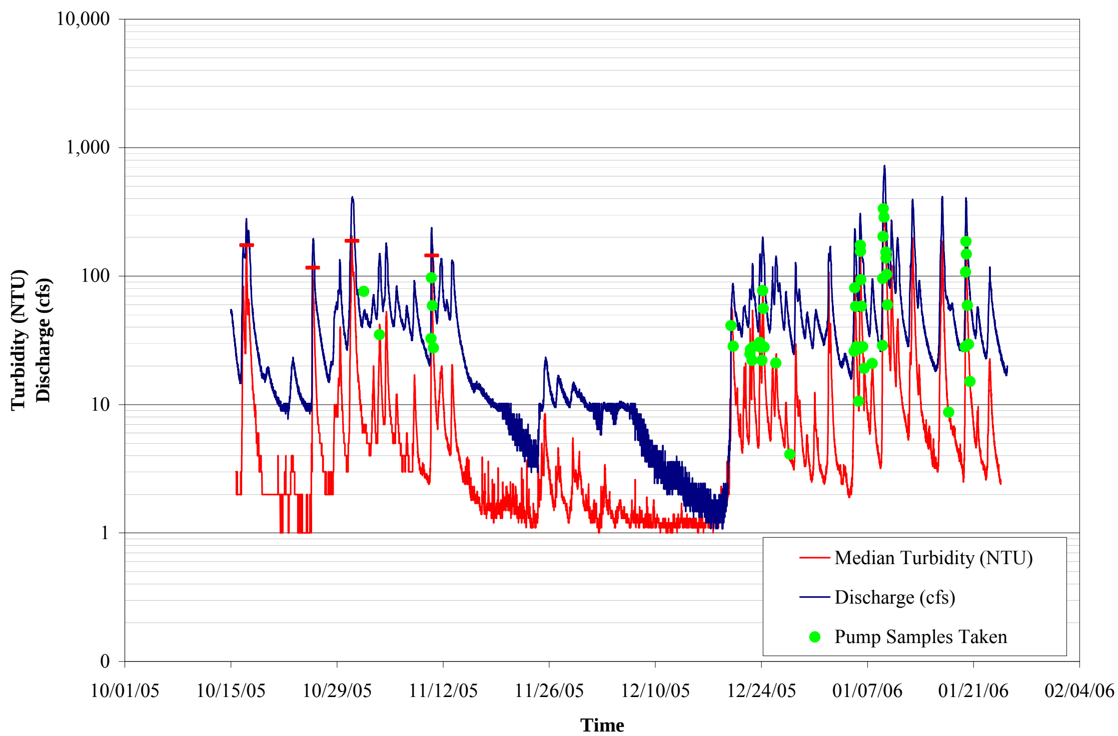

Figure 4.81. Provisional continuous turbidity and stream discharge data for Coal Creek (source: MFM, unpublished data).

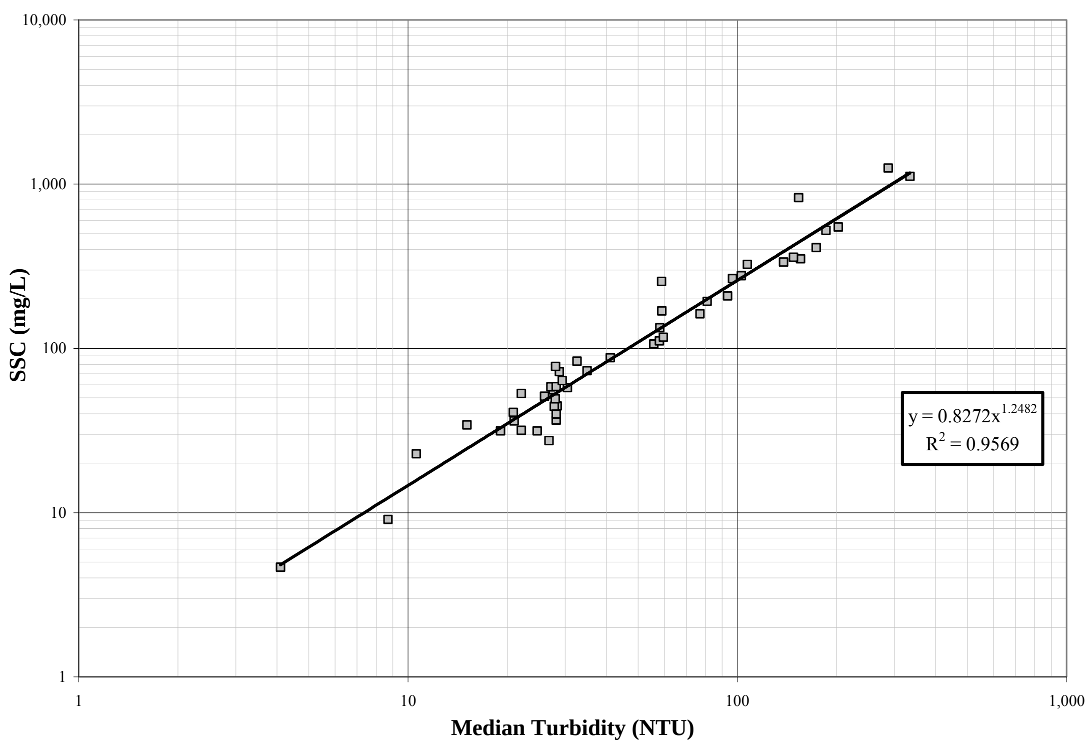

Figure 4.82. Relationships between median turbidity and SSC at Coal Creek (source: MFM, unpublished data).

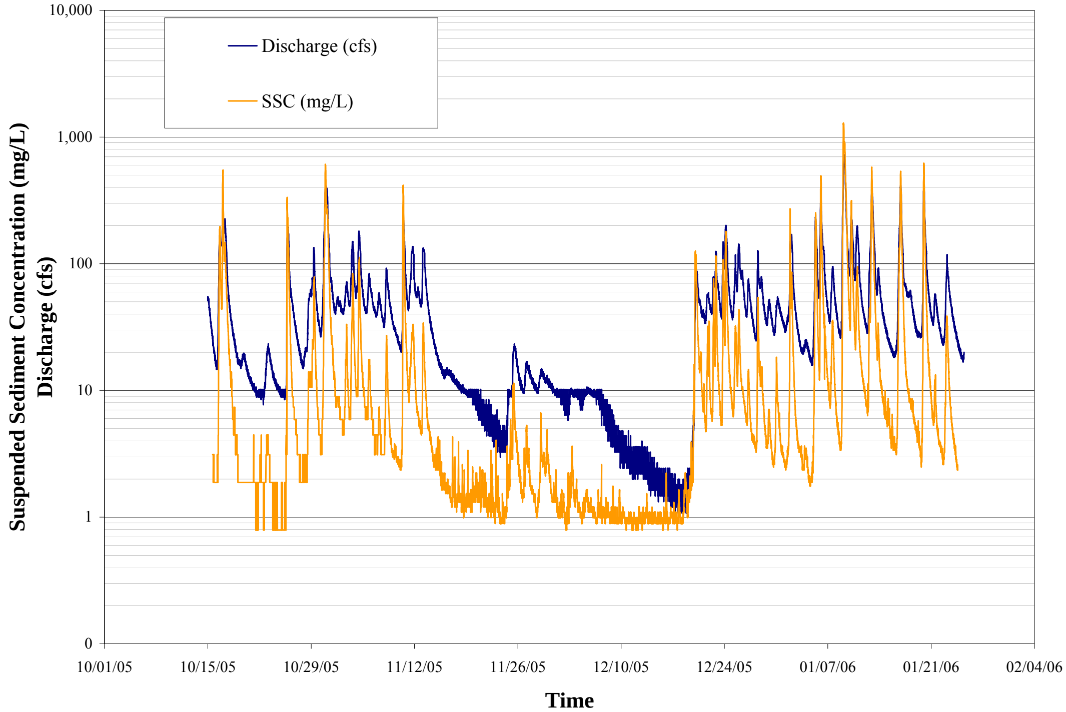

Figure 4.83. Provisional SSC and stream discharge data for Coal Creek (source: MFM, unpublished data).

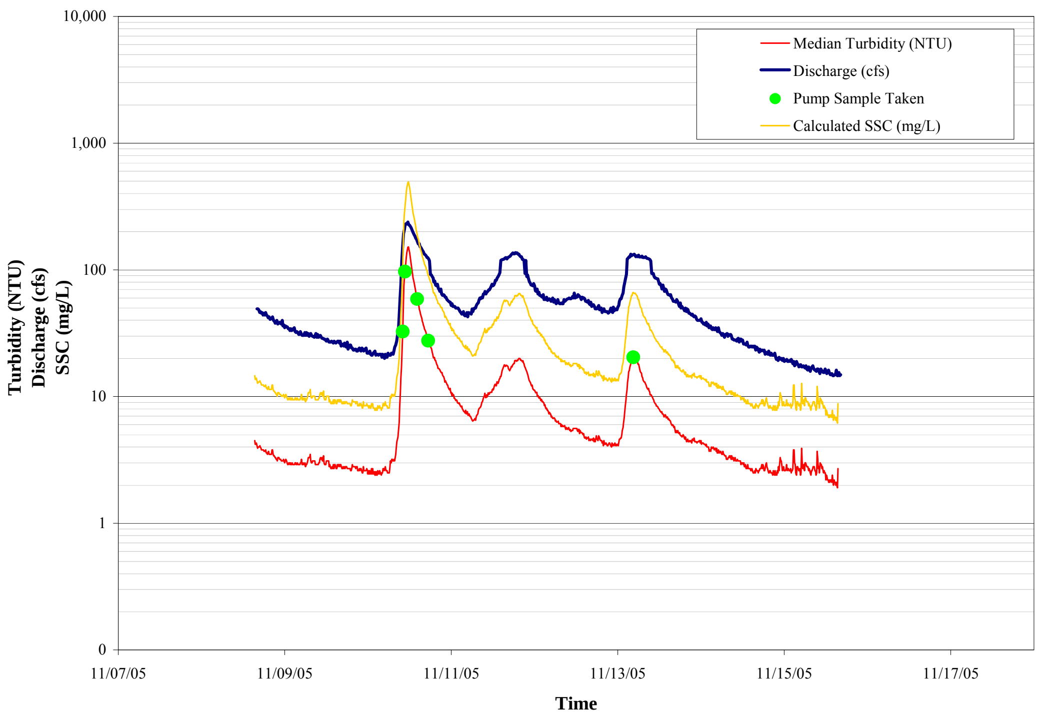

Figure 4.84. Turbidity, discharge, and calculated SSC during a Coal Creek storm event (source: MFM, unpublished data).

4.4.4.6 *Coal Creek Hydrology and Streamflow*

Makah Fisheries Management installed a continuous stream gage on Coal Creek above Ozette River on 12/18/2003 (Figure 4.12). This gage automatically measures and records river stage every 15 minutes. Discharge (ft^3/s) measurements are periodically taken at this location using current meters and wading rods at low to moderate flows, and current meters and bridgeboard cable equipment at high flows. These discharge data, along with continuous stage data, have been used to create a stage-discharge rating curve or a correlation between stage and discharge. The extreme upper end of the rating curve is defined using standard slope-area measurement techniques (Linsley et al. 1982; Sturm 2001), but still needs further refinement using current meter measurements (i.e., results are provisional). Instantaneous discharge at Coal Creek for water years 2004 and 2005 are plotted in Figure 4.85.

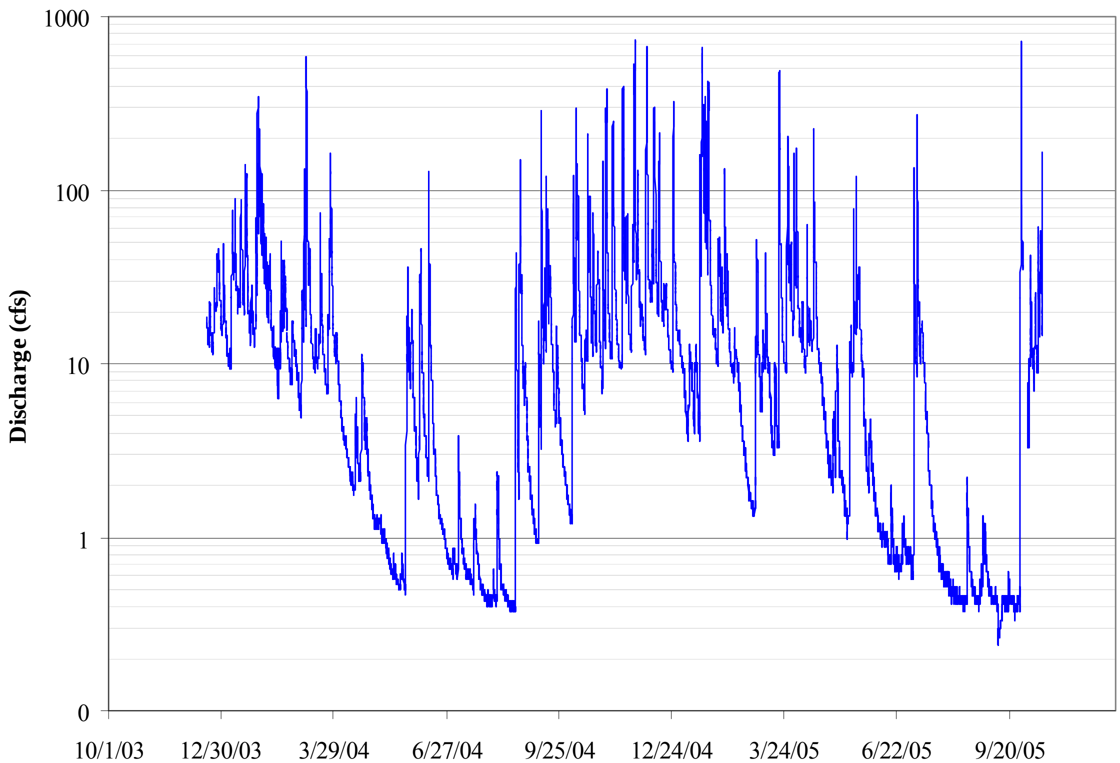

Figure 4.85. Provisional Coal Creek discharge data (source: MFM, unpublished hydrologic data).

4.4.5 Siwash Creek

Siwash Creek drains 2.87mi^2 (7.43km^2) of land and is the fifth largest tributary to Lake Ozette (Table 1.1; Figure 3.16). Siwash Creek enters the lake along the south end of the eastern shoreline of the lake, at a small point just south of Olsen's Beach. The lower 2 miles of Siwash Creek flow to the west, in a valley confined by small hills underlain by Pleistocene age glacial till deposits. Side tributaries draining from the south originate in moderately steep, low hills underlain by Eocene-Miocene aged marine sedimentary rock units. The stream winds around a resistant bedrock knob in a narrow ravine between river mile 2 and 3. Upstream of the ravine, the channel flows through a wide unconfined valley underlain by Pleistocene age glacial till and outwash deposits. Siwash Creek is currently not used by sockeye salmon, but it supports the largest run of kokanee spawners in the Lake Ozette watershed. Detailed information for Siwash Creek is included in this report mainly because of its robust population of kokanee. Documenting and understanding habitat elements that are capable of sustaining a healthy population of kokanee may provide critical insight into factors affecting tributary spawning sockeye salmon in the watershed. In addition, Siwash Creek enters Lake Ozette within a quarter mile of Olsen's Beach and is a potential source of fine sediment to the Olsen's Beach.

4.4.5.1 Siwash Creek Floodplain Conditions

No comprehensive field-based assessment of Siwash Creek floodplain conditions has been conducted. Smith (2000) does not provide an overall rating for floodplain conditions in Siwash Creek. Herrera (2006) reported that the lower 0.25 mile (0.5 km) of Siwash Creek has undergone approximately 3.3 feet (1m) of channel incision over the last 50 years. Herrera (2006) described floodplain connectivity as "fair" for Siwash Creek upstream of the incision near the lake. Lower Siwash Creek averages 7.2 to 8.5 meters BFW (Haggerty and Ritchie 2004) and the associated floodplain is small. Martin Environmental (1999) measured flood prone width in the lower 1.5 miles of Siwash Creek; minimum and maximum widths were 69 ft (21 m) and 357 ft (109 m), respectively.

4.4.5.2 Siwash Creek Riparian Conditions

Riparian conditions in Siwash Creek are highly altered from their historical conditions. The vast majority of the old growth riparian forest has been clear-cut along the mainstem and tributaries. Forest age structure is similar to that seen in other Ozette sub-basins where most of the forest stands are less than 50 years old. Smith (2000) reports that 83% of the forest within the Siwash Creek watershed is less than 20 years old. Orthophotos taken in the summer of 2000 reveal that large portions of the riparian area are dominated by young stands of red alder. Unlike in many Ozette tributaries, there are still a few stands of residual large conifer trees within the watershed. Some riparian forests were retained in the lower mile of Siwash Creek during logging operations. Prior to timber harvest, riparian forests were primarily composed of Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*). Residual in-channel LWD and intact riparian areas in the lower watershed provide evidence of the massive trees that once grew along Siwash Creek.

4.4.5.3 Siwash Creek Pool and LWD Conditions

Pool and LWD habitat data were collected by the Makah Tribe during the summer of 2000 in Siwash Creek and are summarized in detail by Haggerty and Ritchie (2004). Channel data were collected in over 2.8 miles (4.6 km) of channel within the mainstem of Siwash Creek. Channel attribute data for Lake Ozette tributaries can be found in Appendix D. LWD and habitat data were collected in 5 habitat segments encompassing 1.9 miles of channel (only channel data were collected in segment 5; see Figure 4.86). A total of 1,757 pieces of LWD were inventoried, of which 69%, 25%, and 6% were categorized as conifer, deciduous, and unknown, respectively. Just over 4% of the pieces inventoried were classified as key pieces. Approximately 74% of the pieces inventoried were <50cm in diameter. Haggerty and Ritchie (2004) developed a habitat and LWD rating system to evaluate habitat and LWD conditions within the watershed. The results are included in Appendix E. Figure 4.86 depicts the frequency of LWD > 50 cm diameter and total LWD piece frequency per 100 meters for each habitat segment in Siwash Creek.

Pool habitat conditions were also evaluated for the same habitat segments mentioned above. Haggerty and Ritchie (2004) rated several pool habitat condition variables, including pool frequency, percent pools (by length), average maximum and residual pool depth, average pool length, pools >1m deep/km, pool cover, and percent of pools formed by LWD. Figure 4.87 depicts pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in Siwash Creek.

A total of 80 pools were inventoried in the mainstem. The average maximum pool depth was 1.02 meters (residual pool depth=0.88m) and the average pool length was 30.8 meters. Many pools were complex and contained multiple scour pockets, thereby increasing pool length (and percent habitat area) and decreasing pool frequency. The quality of pool habitat appears to be directly related to LWD conditions. The best pool conditions were typically associated with the largest LWD. Nearly 57% of key-piece-sized LWD formed pools, while only 5% of small LWD were classified as pool forming. No pools were formed by small LWD independent of larger LWD. Large LWD (diameter > 50 cm) made up 26% of the total LWD piece count but formed 83% of all pools, the highest observed percentage in any stream system surveyed in the Ozette watershed. Approximately 93% of pool habitat was formed by LWD; only 5% of the total pool habitat was formed independent of LWD (2% of the pool habitat was classified as free-formed w/LWD).

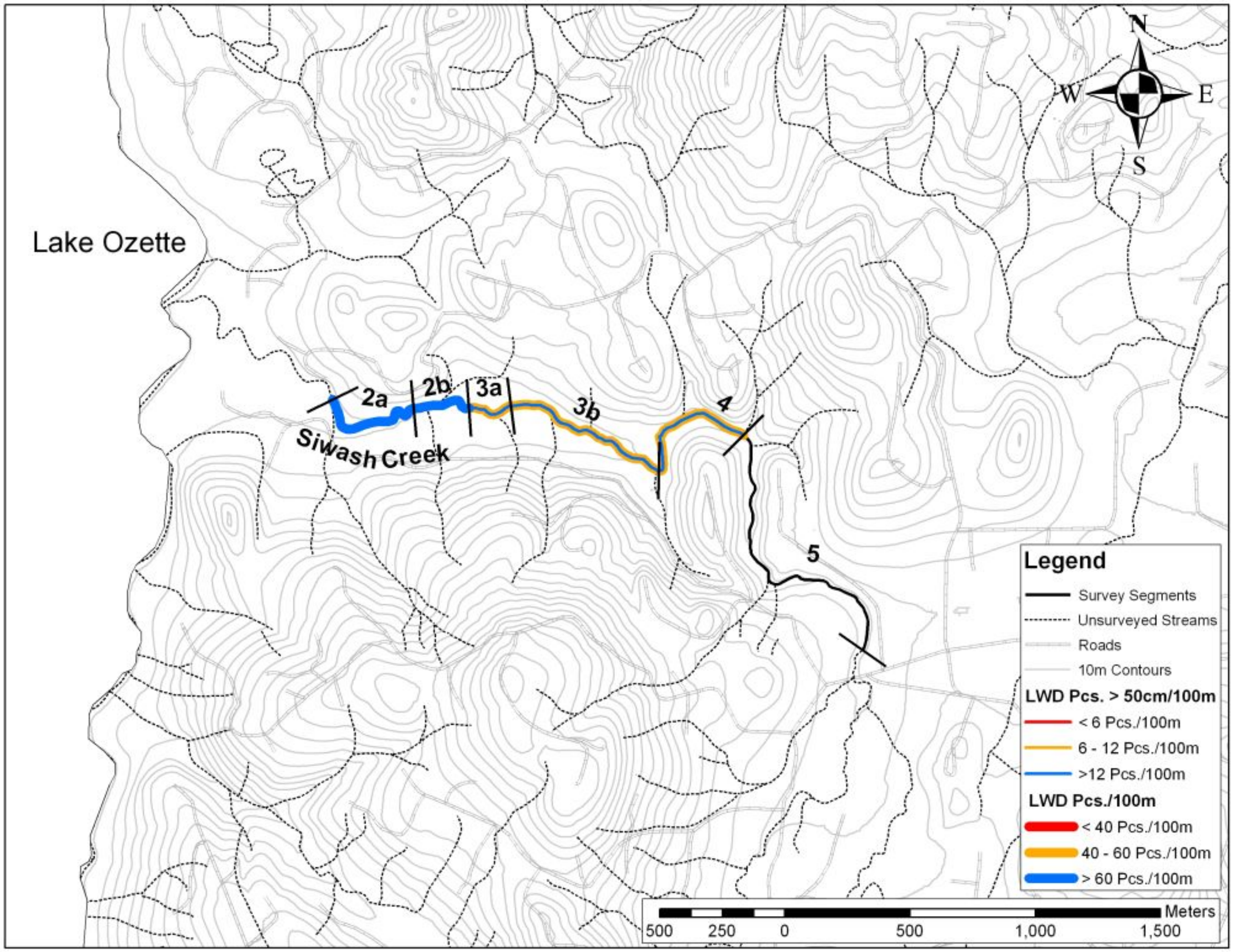

Figure 4.86. Siwash Creek watershed LWD >50cm diameter and total LWD piece count per 100 meters calculated for each habitat segment inventoried (source: Haggerty and Ritchie 2004).

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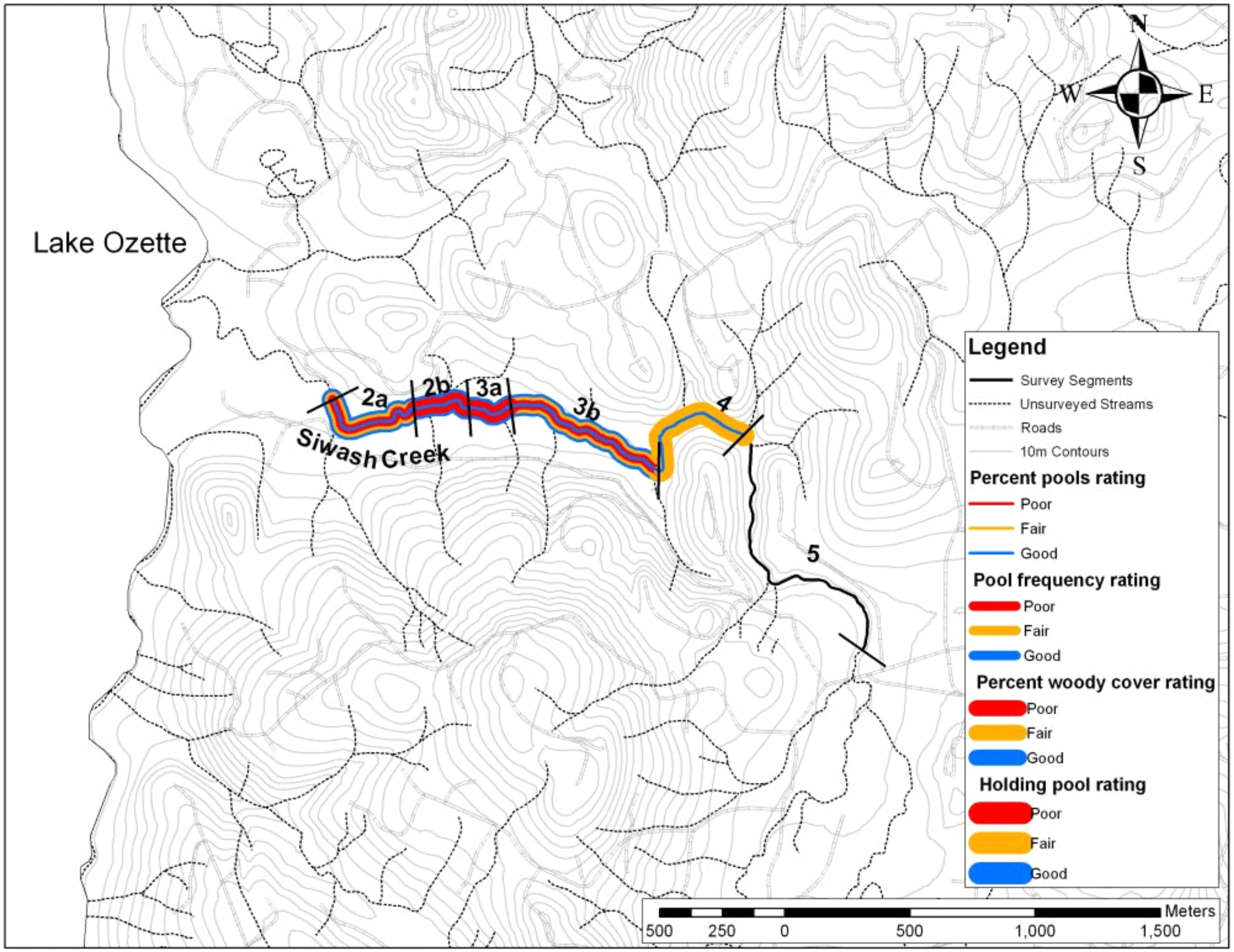

Figure 4.87. Pool habitat condition ratings for percent pools, pool frequency, percent woody cover, and holding pool frequency for channel segments surveyed in Siwash Creek (source: Haggerty and Ritchie 2004).

4.4.5.4 Siwash Creek Streambed and Substrate Conditions

Recent data regarding Siwash Creek substrate conditions are limited to general substrate classifications based on field surveys conducted by MFM (*in* Haggerty and Ritchie 2004) and Martin Environmental (1999). Dominant substrate conditions in segment 1 (see Figure 4.86) of Siwash Creek were classified as 100% gravel by Martin Environmental (1999). Haggerty and Ritchie (2004) found that segments 2 through 4 were dominated by gravel substrate. Segment 5 is dominated by cobble and boulders with a minor gravel component. McHenry et al. (1994) sampled substrate conditions in the lower half of segment 2a (in Figure 4.86). A total of ten samples were collected from representative pool tailouts and/or glides where suitable spawning habitat was present. McHenry et al. (1994) reported the percent fine sediment (>0.85mm) in Siwash Creek averaged 24.0% (wet-sieve equivalent; actual dry-sieve method equal to 13.9%). Smith (2000) rated Siwash Creek "poor" for fine sediment levels in spawning gravel. The current (2006) estimated road density for the Siwash Creek watershed is 5.7 mi/mi^2 (3.5 km/km^2; Ritchie, unpublished data).

4.4.5.5 Siwash Creek Water Quality

Water quality data have been collected in Siwash Creek intermittently from the mid-1970s to present. Early data collected by Bortleson and Dion (1979) are quite limited for Siwash Creek. The most comprehensive water quality dataset is summarized by Meyer and Brenkman (2001). Meyer and Brenkman (2001) collected water temperature, dissolved oxygen, pH, specific conductivity, and turbidity data monthly from July 22, 1993 through October 18, 1994. Table 4.20 contains a summary of water quality sampling data for Siwash Creek from Meyer and Brenkman (2001). Additional stream temperature monitoring was also conducted using a thermograph and data logger during the summer of 1994 (Figure 4.88). .

Table 4.20. Summary of water quality data collected in Siwash Creek from July 22, 1993 through October 18, 1994 (source: Meyer and Brenkman 2001).

	Stream Temperature (°C)	**pH**	**Specific Conductivity (uS/cm)**	**Dissolved Oxygen (mg/l)**	**Turbidity (NTU)**
Minimum	3.7	6.2	25.1	9.4	0.0
Maximum	15.1	7.3	73.0	11.4	22.0
Mean	10.3	6.8	52.6	10.2	5.6
Number of Samples	n=18	n=13	n=17	n=14	n=13

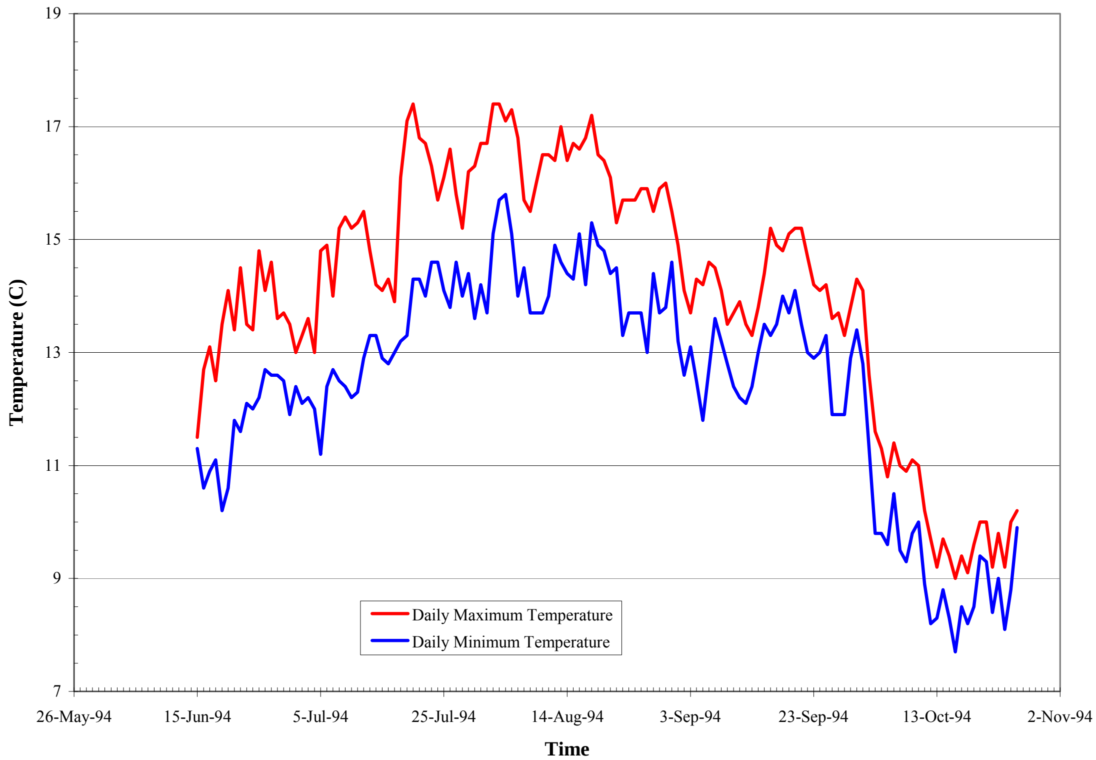

Figure 4.88. Siwash Creek daily maximum and minimum stream temperature data near ONP boundary (source: Meyer and Brenkman 2001).

Makah Fisheries Management installed a continuous submersible turbidity sensor on Siwash Creek on State Land on 04/21/2005, with the goal of detecting long-term (5-10 plus year) trends in turbidity and suspended sediment concentration. The sensor is deployed from a bank-mounted boom that reaches out over the channel and places the sensor toward the center of the channel in well-mixed water. (Methods used are similar to those in Big River and Umbrella Creek. For additional details see Sections 4.4.1.5 and 4.4.2.5.)

Median turbidity values (15-minute) from Siwash Creek are plotted in Figure 4.89, along with discharge from Crooked Creek. Turbidity (and SSC) peaks in Siwash Creek usually last for less than a day, depending on the length of the flood pulse event. Turbidity rises sharply on the rising limb of the discharge hydrograph and falls more rapidly than discharge on the recession limb. These lower turbidity (and SSC) values on the recession limb at the same discharge (i.e., hysteresis) are a result of the initial flush of readily available sediment from both upland and channel sources (Hicks and Gomez 2003). Thus in Siwash Creek, turbidity and suspended sediment concentrations are dependent on the supply of fine sediment from both upland and channel sources.

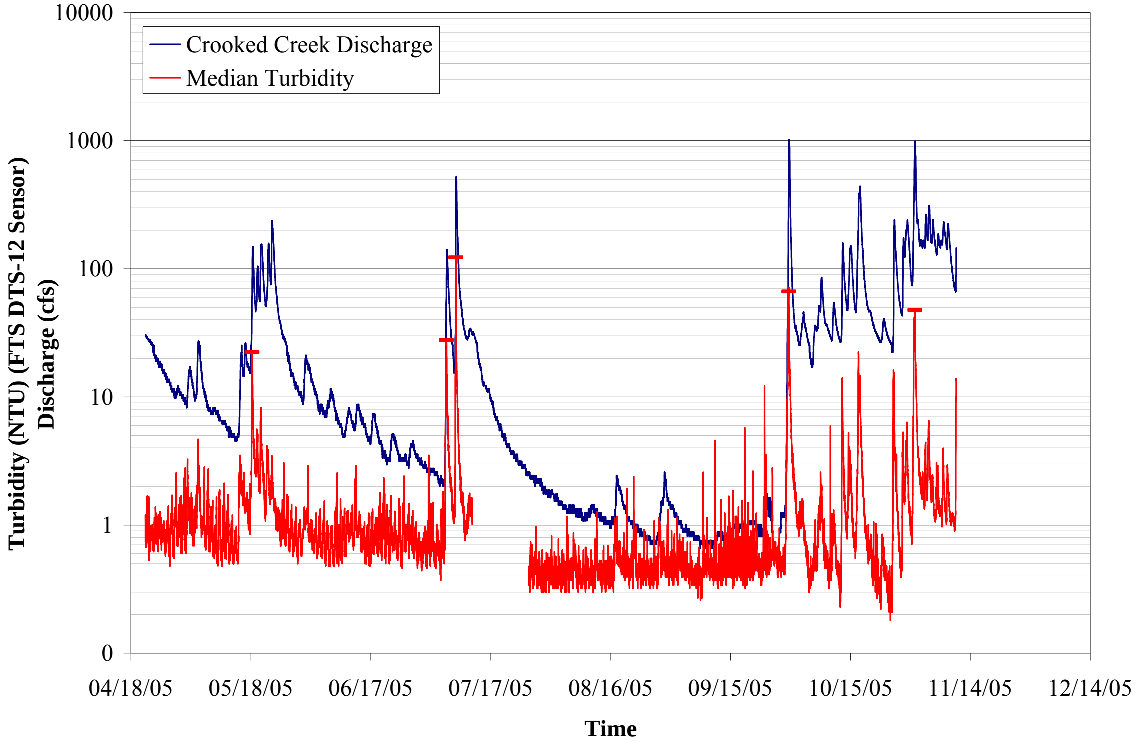

Figure 4.89. Provisional Siwash Creek continuous turbidity data contrasted with Crooked Creek stream discharge data (source: MFM, unpublished data).

4.4.5.6 Siwash Creek Hydrology and Streamflow

No continuous streamflow data are available for Siwash Creek. Meyer and Brenkman (2001) collected instantaneous discharge measurements in several Ozette watershed streams in 1993 and 1994. Figure 4.90 depicts instantaneous stream discharge measurements for Umbrella, Crooked, Siwash, and South creeks from 1993 to 1994. Streamflow in South and Siwash creeks are very similar to one another, whereas streamflows in Umbrella and Crooked Creek are generally higher than those measured in Siwash Creek.

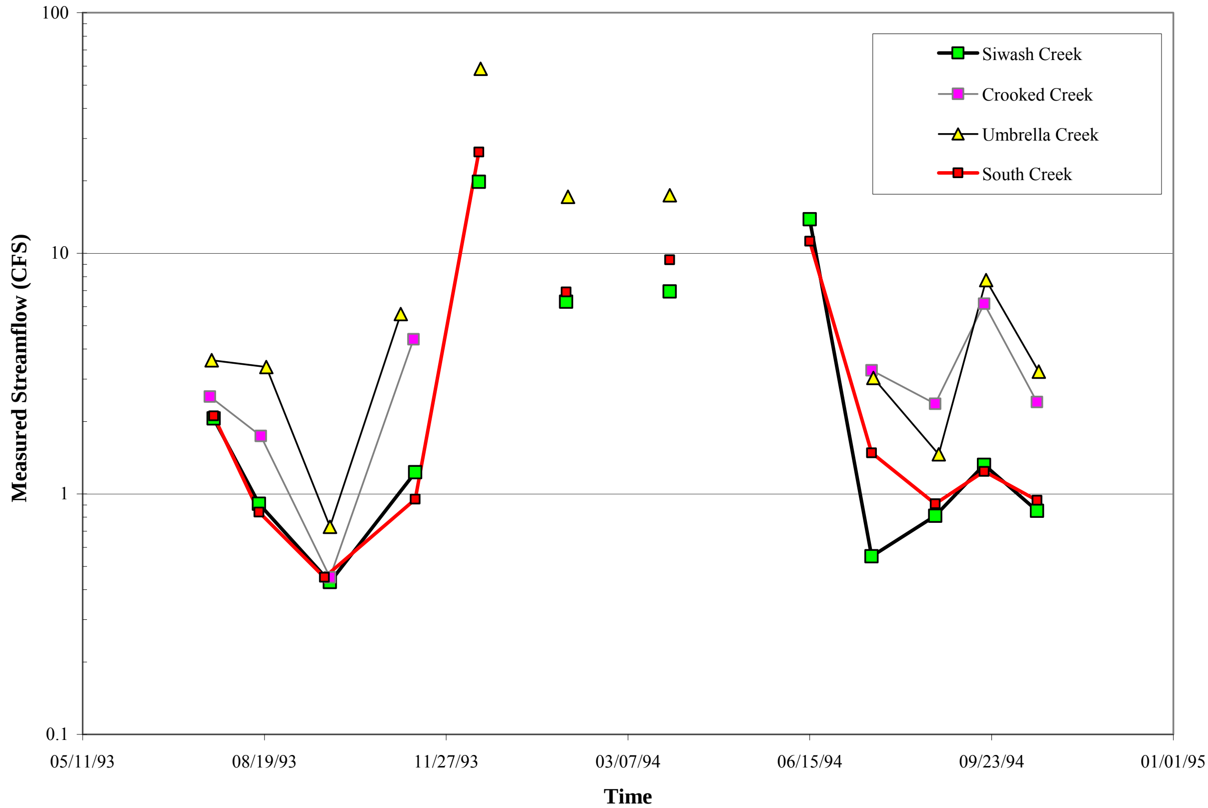

Figure 4.90. Instantaneous discharge measurements for Siwash, Crooked, Umbrella, and South Creeks (source: Meyer and Brenkman 2001)